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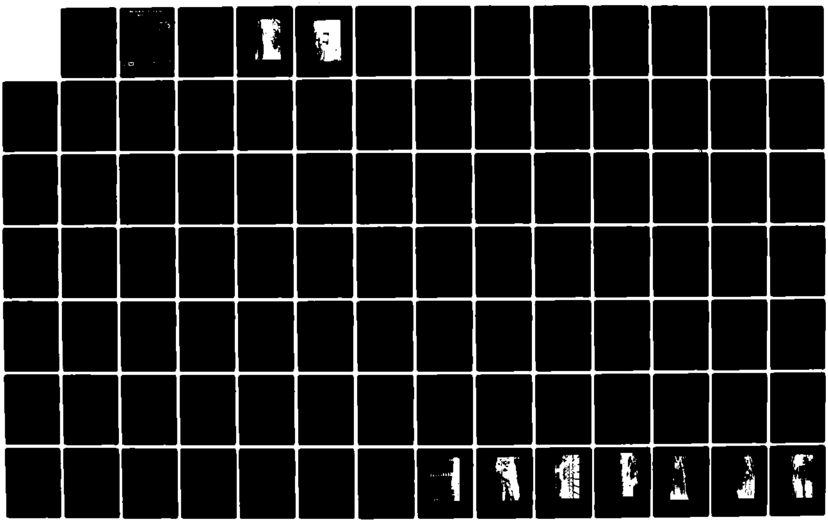

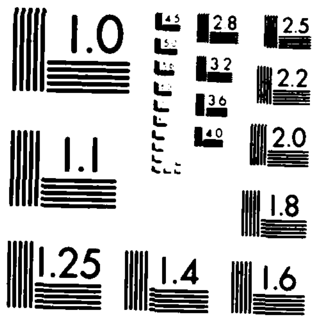

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 196- A

EMBANKMENT CRITERIA AND PERFORMANCE REPORT

SEPTEMBER 1982

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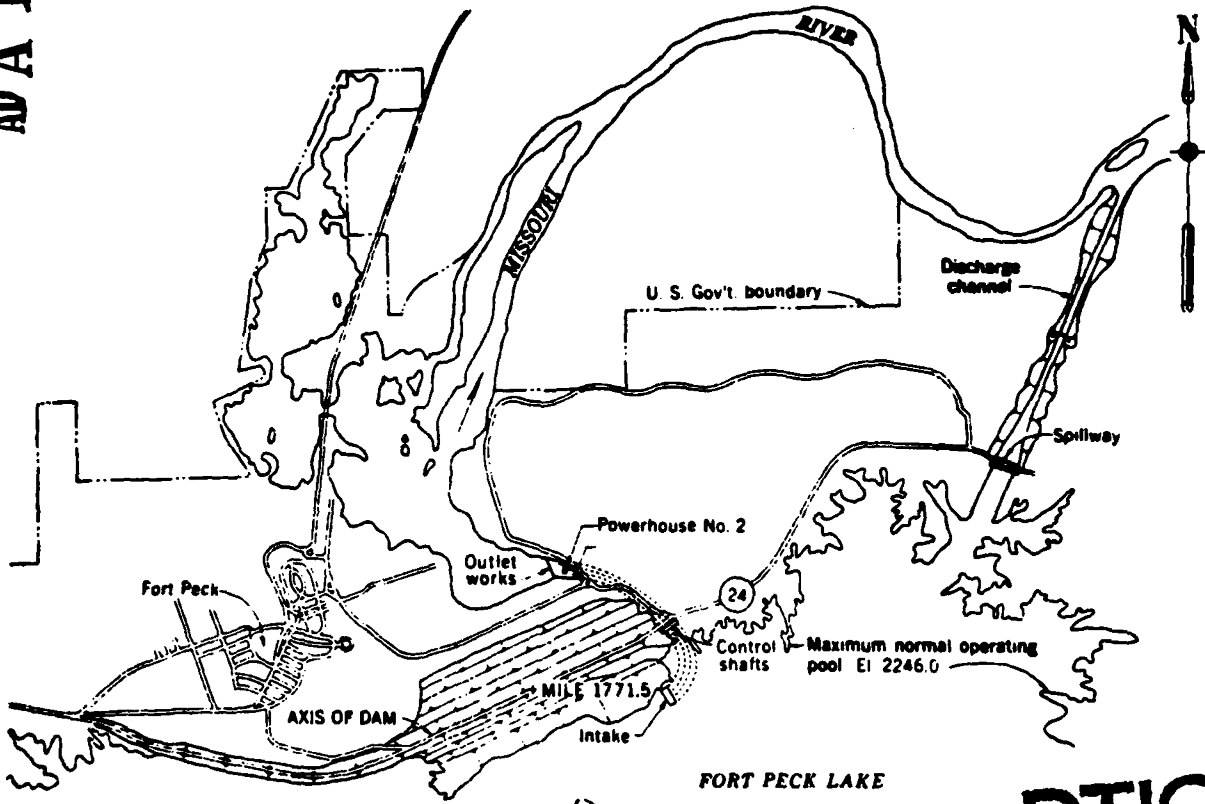
MISSOURI RIVER
FORT PECK LAKE, MONTANA



US Army Corps of Engineers
Omaha District

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DISK 405C
Project C6552

FORT PECK LAKE

MISSOURI RIVER, MONTANA

EMBANKMENT CRITERIA

AND

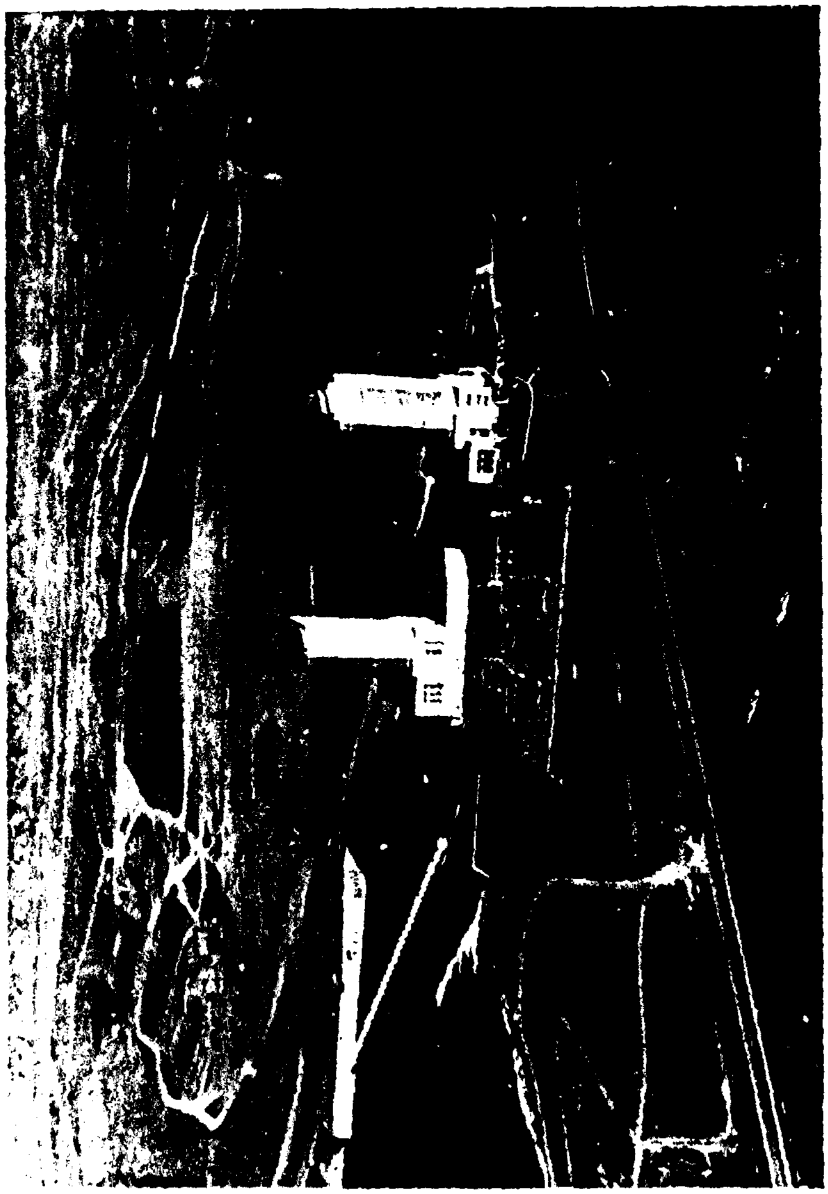
PERFORMANCE REPORT

SEPTEMBER 1982

General aerial view of Fort Peck Dam and Lake, looking west

FORT PECK DAM, MONTANA
EMBANKMENT CRITERIA
AND PERFORMANCE REPORT

PLATE 1



Aerial view, looking north, showing Tailrace, Switchyard and Powerhouses

FORT PECK DAM AND RESERVOIR

MISSOURI RIVER BASIN, MONTANA

Embankment Criteria and Performance Report

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FORT PECK DAM AND LAKE
MISSOURI RIVER, MONTANA

PERTINENT DATA

Authorization. The Fort Peck Lake Project was recommended by the Chief of Engineers, 30 September 1933; authorized by the Public Works Administration, 24 October 1933; approved by the River and Harbor Act, 30 August 1935 (House Document 238, 73rd Congress, 2nd Session); and amended by the Act of 18 May 1938 (Public Law 529, 75th Congress, 3rd Session) and by the Act of 3 June 1948 (Public Law 586, 80th Congress). The project consists of an earth dam, flood control tunnels, spillway, powerplant, and multiple-purpose reservoir operated as a unit in the comprehensive plan for flood control, irrigation, navigation, power, and other uses.

Location. The project is located on the Missouri River at River Mile 1771.5 in McCone and Valley Counties, Montana, 20 miles (32 kilometers (km)) southeast of Glasgow, Montana.

Embankment.

Top of Dam	Elevation 2280.5 feet (ft) mean sea level (m.s.l.)
Length of Dam (Including Dike Section)	21,026 ft or 6,413 meters (m)
Damming Height (Low Water to Maximum Pool)	220 ft or 67 m
Maximum Height	250.5 ft or 76 m
Type of Fill	Hydraulic and Rolled Earth
Fill Quantity	125,628,000 cubic yards (cu. yd.) or 95,625,000 cubic meters (m^3)
Width at Crest	50 ft or 15 m
Width at Base	4,900 ft or 1,495 m
Date of Closure	24 June 1937

Spillway.

Location	3 miles or 4.8 km east of dam
Type	Concrete-lined chute with gated weir
Design Discharge Capacity	250,000 cubic feet per second (c.f.s.) or 7,000 m^3s
Crest Elevation	2,225 ft m.s.l.
Width (Including Piers)	820 ft or 250 m
Gates (Stoney)-Number and Size	16 - 25 ft (7.6m) by 40 ft (12.2 m)
Gate Operating Machinery	Motor-operated with individual hoists and counterweights

Outlet Works.

Tunnels-Number and Size	Two - 24 ft (7.3 m)
Tunnel Length (Inlet Portal--Station 0+07--to Outlet Portal)	
No. 3	6,614.78 ft or 2,018 m
No. 4	7,239.66 ft or 2,208 m
Control Gates, Cylindrical, One for Each Tunnel-Size	12 ft (3.7 m) by 28 ft (8.5 m) (diameter)
Maximum Discharge Capacity per Tunnel of Elevation 2,250 ft m.s.l. and 9.35 ft (2.9 m) Opening	22,500 c.f.s. or 630 m^3s

Power Facilities.

Powerplant No. 1

Power Tunnel Size	24.66 ft (7.5 m) dia.
Power Tunnel, Lengths (Inlet Portal—Station 0+07--to Turbine Spiral Case)	
Unit No. 1	5,662.0 ft or 1,727 m
Unit No. 2	5,646.3 ft or 1,722 m
Unit No. 3	5,636.7 ft or 1,719 m

Power Penstocks-Number and Size (Penstocks Formed by a Wye-Branch at End of Power Conduit)	
No. 2	One - 11 ft (3.4 m) dia.
Nos. 1 and 3	Two - 14 ft (4.3 m) dia.
Number of Power Tunnel Gates (for Emergency Use Only)	Two - Vertical lift tractor
Gate Size	24 ft (7.3 m) high by 11.5 ft (3.5 m) wide
Penstock Butterfly Valves-Number and Size	Two - 16 ft (4.9 m) dia. One - 12 ft (3.7 m) dia.
Average Gross Head Available	205 ft (62.5 m)
Turbines-Number, Type, and Rated Speed	Three - Francis, two rated at 128.5 revolutions per minute (r.p.m.) and the other at 164 (r.p.m.)
Surge Tanks (One Each Penstock; 40 ft (12.2 m) dia. All Interconnected)	Three
Plant Capacity at Reservoir Elevation 2,246.0 ft m.s.l. (two at 50,000 kilowatts (kw) and one at 21,000 kw)	121,000 kw total*
Year of Initial Power Generation	1943

<u>Powerplant No. 2</u>

Power Tunnel Size	22.3 ft (6.8 m) dia
Power Tunnel, Length Units 4 and 5 (Inlet Portal--Station 0+07--to Turbine Spiral Case)	6,309.5 ft or 1,924 m

*(Operational limitations at 118,000 kw at reservoir elevation 2,242.0 ft (m.s.l.))

Power Penstocks-Number and Size (Penstocks Formed by a Wye-Branch at End of Power Conduit)	Two - 15.83 ft (4.8 m) dia.
Number of Power Tunnel Gates (for Emergency Use Only)	Two
Gate Size	24 ft (7.3 m) high by 11.5 ft (3.5 m) wide
Penstock Butterfly Valves- Number and Size	Two - 18 ft (5.5 m) dia.
Average Gross Head Available	205 ft (62.5 m)
Turbines-Number, Type, and Speed	Two - Francis at 128.6 r.p.m.
Surge Tanks (All Interconnected)	Two - 65 ft (20 m) dia.
Plant Capacity (Two at 40,000 kw)	80,000 kw
Year of Initial Power Generation	1961

Reservoir.

Drainage Area.

Above Fort Peck Dam	57,725 square miles (sq. mi.) (149,508 km2)
Maximum Operating Pool Elevation	2,250 ft m.s.l.
Minimum Operating Pool Elevation	2,160 ft m.s.l.
(Usual Range of Pool Fluctuation)	2,234 to 2,246 ft m.s.l.
Pool Area at Maximum Operating Elevation	247,000 acres (acre) 100,000 hectacres (ha)
Pool Area at Minimum Pool Elvation	93,000 acre (37,665 ha)
Length of Pool at Maximum Operating Pool Elevation	138 miles (222 km)
Shoreline, Miles at Elevation 2,250 ft m.s.l.	1,600 miles (2,576 km)

Reservoir Storage	Elevations, (ft m.s.l.)	Capacity, Acre-Feet (m^3)
Allocations.		
Exclusive Flood Control	2246-2250	900,000 (1.1×10^9)
Seasonal Flood Control	2234-2246	2,800,000 (3.5×10^9)
Carryover Multiple Use	2160-2234	11,100,000 (1.4×10^{10})
Inactive Storage	2030-2160	4,300,000 (5.3×10^9)
Gross Storage	2030-2250	19,100,000 (2.4×10^{10})

SECTION I - INTRODUCTION

1.1 **PURPOSE AND SCOPE OF REPORT.** The purpose of this report is to provide, within one volume, the significant information needed by engineers to (1) familiarize themselves with the project, (2) reevaluate the embankment in the event of unsatisfactory performance; and (3) obtain guidance for designing comparable future projects. The scope includes summary records of significant design data, design assumptions, design computations, specification requirements, construction procedures, construction experience, and field control test data.

1.2 **PROJECT LOCATION.** The Fort Peck Dam is located on the Missouri River about 11 miles (17.7 kilometers (km)) above the mouth of the Milk River, in northeastern Montana. It is 69 miles (111 km) south of the international boundary and 111 miles (180 km) west of the North Dakota Line. With respect to the United States land surveys, the project location is near the center of T .26 N., R .41 E., as shown on Missouri River Basin Map, plate 1-1. The coordinates upstream from the axis of the dam are designated as Range U and downstream from the axis, as Range D. The coordinates along the axis are measured from a point on the right abutment. The Missouri River, at the site of the dam, flows in a northly direction. The dam construction grid system is shown on plate 1-2.

1.3 **PROJECT PURPOSES.** The authorized purposes for the project are flood control, power, irrigation, navigation, and other purposes.

1.4 **PROJECT AUTHORIZATION.** The Fort Peck Project was originally authorized for navigation, incidental flood control, and power. The project with these purposes was:

1.4.1 Recommended by the Chief of Engineers, 30 September 1933;

1.4.2 Approved by the President of the United States by Executive Order on 14 October 1933; and

1.4.3 Approved in River and Harbor Act on 30 August 1935 (House Document 238, 73rd Congress, 2nd Session).

The project purposes were modified in the 1944 Flood Control Act (Public Law No. 534, 78th Congress, 2nd Session) from "navigation, incidental flood control, and power" to "flood control, power, irrigation, navigation, and other purposes."

1.5 ESTIMATED COST.

Basic project	$132,514,800
Recreation at Completed Projects	2,019,000
Total Federal Cost	$134,533,800

SECTION II - PROJECT DESCRIPTION

2.1 **GENERAL.** The main control features of the Fort Peck Dam and Reservoir are the embankment, a gated concrete spillway, two hydroelectric generating plants, and the flood control outlet works. These principal features are shown on plate 2-1.

2.2 **EMBANKMENT.** The 250-foot (76 meter (m)) high embankment has a total crest length of 21,000 feet (ft) (6,405 m) at elevation 2280.5 ft mean sea level (m.s.l.), is 4,900 feet (1,494 m) wide at the base tapering to 50 feet (15 m) wide at the crest, and contains 125,600,000 cubic yards (cu. yd.) (96,000,000 cubic meters (m^3)) of earthfill.

2.3 **GATED CONCRETE SPILLWAY.** The 820-foot (250 m) wide reinforced concrete spillway, with a crest elevation of 2225 ft (m.s.l.) and sixteen 25-foot (8.2 m) by 40-foot (12 m) electrically operated vertical-lift steel gates, is a safety valve to ensure that unprecedented floodflows will not overtop the dam. This structure is capable of discharging 230,000 cubic feet per second (c.f.s.) (6,440 cubic meters per second (m^3s), with the reservoir at elevation 2250.0 ft m.s.l.

2.4 **HYDROELECTRIC GENERATING PLANT.** The two powerplants, located in the right abutment, house five generating units with a combined capacity of 165,000 kilowatts (kw).

2.5 **FLOOD CONTROL OUTLET WORKS.** The outlet works, located in the right abutment, consists of two each concrete-lined tunnels, intake structures, control shafts, and an outlet channel.

2.6 **RESERVOIR STORAGE CAPACITY.** The full storage capacity of the Fort Peck Reservoir with the pool at elevation 2250.0 ft m.s.l. is 19,100,000 acre-ft ($2.3 \times 10^{10} m^3$). The 900,000 acre-ft ($1.1 \times 10^9 m^3$) available between elevations 2246 and 2250 ft m.s.l. is usually reserved for flood control.

SECTION III - SITE GEOLOGY

3.1 FOUNDATION EXPLORATIONS. The foundation exploration for the Fort Peck Dam was accomplished by contract drilling, except for limited foundation drilling by Government plant and hired labor. The foundation exploration contracts are summarized in table 3-1.

TABLE 3-1

EXPLORATION CONTRACTS - FORT PECK DAM

Contractor	Exploration Areas	No. of Holes	Total Depth feet/meters
E. J. Longyear	Valley and Abutments (Embankment Area)	42	6,100/1,860
S. J. Mathews	Tunnels and Embankment Foundation	182	8,600/2,625
Mott	Tunnel, Shaft, and Portal Area	30	4,700/1,435
Diamond	Valley and Left Abutment of Embankment; Borrow Areas	224	26,300/8,020
E. J. Longyear	Three Possible Spillway Sites	75	11,000/3,355

3.2 FOUNDATION OVERBURDEN. Foundation borings showed that practically the entire base of the dam was covered with a clay blanket. The left bank clay was derived, in most part, from the glacial-till bluffs. On the right bank, the clay was derived principally from the shale bluffs. Both types of clay were relatively impervious and had relatively low shear strength when saturated. The borings also showed that the underlying flood plain materials consisted of gravels, sands, and silts to a maximum depth of 160 ft (49 m). This alluvial material overlies the Bearpaw shale bedrock, which is estimated to be 1,000 ft (305 m) thick in this region.

3.3 **FOUNDATION BEDROCK.** The Bearpaw shale dips east at about 3 ft (0.9 m) per mile (1.6 km) so, for all practical purposes, the formation can be considered horizontal. It is interspersed with thin layers of bentonite and with less numerous thin limestone beds, fossils, and pyrite horizons. Concretions, primarily of clay-iron stone, also are numerous and range from a fraction of an inch to several feet in diameter.

In its unweathered state, the Bearpaw shale is a firm clay shale which is usually considered as a weak rock. The shale has conchoidal fracture and can be slightly dented with a fingernail. The dry density of unweathered Bearpaw shale ranges from about 116 to 124 pounds per cubic foot (p.c.f.) (1877 to 2006 kilograms per cubic meter (kgm^3)) and averages 120 p.c.f. (1941 kgm^3). The moisture content ranges from 11 percent to 18 percent and averages about 15 percent.

The surface of the firm shale weathers readily into sand to gravel sizes on exposure to air and moisture, and with repeated wetting and drying disintegrates into fat clay (gumbo) soil. Weathering effects are most intense at the shale surface but extend to depths of 30 feet (9 m) to 50 feet (15 m). The highly weathered zone is usually limited to a thickness of 10 feet (3 m) to 20 feet (6 m). The transition zone from weathered to firm shale occurs over an interval of several feet. This transition zone is termed subfirm shale. The dry density of the weathered shale is usually less than 100 p.c.f. (1620 kgm^3) and the moisture content ranges from about 20 percent to 40 percent.

The firm shale in its undisturbed state was probably originally horizontal and vertical but can now best be described as irregular. Numerous faults are in the shale. Faults in the valley walls are probably associated with slumping of shale masses that occurred as the river steepened its valley by downcutting. Most of the faults are of the gravity type and typically dip 35° to 60° with an average dip of about 45°.

The index to drill holes is presented in plan on plate 3-1. Plates 3-2 through 3-6 present foundation profiles developed from the Diamond Drill Contract exploratory borings. These profiles represent the best data available concerning the foundation beneath the dam. A tabulation and index of drill hole logs for the foundation investigation is presented on plates 3-7 through 3-19.

Pages 3-4, 3-5 and 3-6 deleted.

FORT PECK DAM

TABULATION AND INDEX OF DRILL HOLE LOGS FOR

FOUNDATION INVESTIGATIONS FOR FORT PECK DAM

Hole No.	Field Book Number	*Log Book Number	*Log Book Page	Contractor	Ground Elevation	Station	Range	Latitude	Departure	Desig-nation	File Location
1	1204	2	22	Longyear	2300.2	1+43.0	0+62.5-D	638,790.3	870,018.5	Tunnel	Box 36
2	1203	2	39	Longyear	2286.8	4+17.8	0+30.0-U	638,591.0	869,807.8	Tunnel	"
3	1208	1	1	Longyear	2083.6	12+05.4	0+62.5-D	638,344.6	869,054.1	Tunnel	"
4	1207-1209	1	35	Longyear	2059.4	18+05.2	0+62.5-D	638,093.0	868,509.6	Axis	"
5	1205	1	48	Longyear	2057.9	24+05.0	0+62.4-D	637,841.3	867,965.2	Axis	"
6	1205-1206	1	46	Longyear	2057.7	30+04.8	0+62.5-D	637,589.7	867,420.7	Axis	"
7	1208	1	12	Longyear	2057.4	36+04.5	0+62.4-D	637,338.1	866,876.3	Axis	"
8	1205	4	1	Longyear	2055.0	42+04.2	0+62.4-D	637,086.5	866,331.9	Axis	"
9	1204	1	42	Longyear	2055.5	49+04.0	0+62.4-D	636,792.9	865,696.7	Axis	"
10	1205-1207	1	27	Longyear	2056.3	55+50.6	0+62.4-D	636,521.7	865,109.7	Axis	"
11	1202	1	9	Longyear	2047.1	73+05.8	0+62.5-D	635,785.5	863,516.4	Axis	"
12	1201	1	17	Longyear	2049.5	78+97.2	0+62.5-D	635,537.4	862,979.5	Axis	"
13	1204-1208	2	1	Longyear	2066.9	84+40.5	0+62.5-D	635,309.5	862,486.4	Axis	"
14	1201	1	19	Longyear	2216.5	95+01.3	0+62.4-D	634,864.4	861,523.5	L Abut	"
15	1205-1206	4	12	Longyear	2221.5	120+70.0	3+13.7-D	634,014.9	859,086.3	L Abut	"
16	1201	2	18	Longyear	2218.5	142+90.3	14+61.2-D	634,125.2	856,589.4	L Abut	"
17	1208	2	13	Longyear	2223.1	163+61.9	33+21.8-D	634,945.1	853,928.5	L Abut	"
18	1207-1208	2	9	Longyear	2271.3	188+26.2	57+29.4-D	636,096.9	850,681.5	L Abut	"
Hole No. 19 through 24 Not Drilled											
25	1208	1	2	Longyear	2148.0	10+30.7	0+03.2-U	638,358.2	869,240.2	Axis	"
26	1206	2	43	Longyear	2311.0	208+22.4	68+62.6-D	636,288.2	848,394.[illegible]	L Abut	"
27	1208	1	3	Longyear	2202.2	8+04.6	1+08.4-U	638,357.6	869,489.6	Tunnel	"
28	1202-1205	1	32	Longyear	2042.8	63+21.1	0+62.3-D	636,198.4	864,410.3	Axis	"
29	1202-1209	1	28	Longyear	2042.3	68+13.7	0+62.4-D	635,991.8	863,963.2	Axis	"
30	1228	101	19	Mathews	2069.8	14+13.3	16+54.8-U	636,698.5	869,585.7	Tunnel	"
31	1235	101	27	Mathews	2072.8	13+53.6	21+49.0-U	636,274.9	869,874.3	Tunnel	"
32	1235	101	39	Mathews	2073.5	13+31.6	26+92.8-U	635,790.5	870,095.4	Tunnel	"
33	1235	109	31	Mathews	2105.3	10+39.6	18+11.0-U	636,713.6	869,990.5	Tunnel	"
34	1235	102	42	Mathews	2111.2	9+79.9	22+58.6-U	636,332.2	870,232.4	Tunnel	"
35	1209	109	15	Mathews	2176.4	7+86.4	19+02 -U	636,737.1	870,258.5	Tunnel	"
36	1209-1228	101	8	Mathews	2081.8	10+77.2	14+13.1-U	637,058.9	869,789.5	Tunnel	"
37	1225	104	30	Mathews	2108.6	6+69.8	16+73.0-U	636,993.9	870,268.3	Tunnel	"
38	1225	105	30	Mathews	2104.2	5+55.4	13+78.9-U	637,308.8	870,248.8	Tunnel	"
39	1221	105	42	Mathews	2095.9	7+94.3	14+42.3-U	637,151.0	870,058.5	Tunnel	"
40	1206	4	48	Longyear	2279.4	205+52.9	56+40.7-D	635,292.1	849,151.3	L Abut	"
41	1206	5	7	Longyear	2246.9	216+72.9	59+01.7-D	635,059.2	848,025.1	L Abut	"
42	1209	5	10	Longyear	2274.1	189+12.3	71+02.3-D	637,307.1	850,027.4	L Abut	"
44	1209	5	12	Longyear	2241.1	178+03.6	80+36.9-D	638,620.5	850,641.7	L Abut	"
49	1209	5	14	Longyear	2277.8	226+59.8	55+73.8-D	634,347.5	847,266.8	L Abut	"
51	1206	5	19	Longyear	2320.8	216+82.3	72+57.2-D	636,285.7	847,447.9	L Abut	"
52	1209	5	17	Longyear	2318.0	214+31.3	77+65.4-D	636,852.3	847,462.6	L Abut	"
53	1209	5	19	Longyear	2326.0	227+43.3	75+47.3-D	636,103.9	846,363.1	L Abut	"
58	1206	4	45	Longyear	2300.3	202+24.7	64+57.7-D	636,171.4	849,106.4	L Abut	"
59	1205-1206	4	18	Longyear	2213.9	104+10.3	8+42.8-U	633,661.4	861,078.0	L Abut	"
60	1205-1206	4	14	Longyear	2186.5	100+10.2	12+85.2-D	635,760.9	860,548.5	L Abut	"
61	1206	4	21	Longyear	2173.5	98+37.9	23+92.0-D	636,837.9	860,240.6	L Abut	"
62	1203	4	24	Longyear	2124.2	105+88.5	18+47.2-U	632,674.9	861,337.6	L Abut	"
63	1203	4	30	Longyear	2080.7	96+37.1	35+15.3-D	637,941.8	859,951.7	L Abut	"
64	1203	4	27	Longyear	2219.8	102+39.7	1+26.4-D	634,612.7	860,826.3	L Abut	"
72	1245	Mott		Mott	2233.7	0+99.8	6+29.8-U	638,179.9	870,348.1	Tunnel	"
73	1225	104	21	Mathews	2116.5	20+22.3	30+22.1-D	640,688.6	867,071.0	Tunnel	"
74	1242	Mott		Mott	2163.6	3+77.2	18+38.0-U	636,966.8	870,603.1	Tunnel	"
75	1242	Mott		Mott	2181.6	1+85.6	12+65.5-U	637,466.9	870,536.9	Tunnel	"
76	1247			Mott	2243.5	5+16.6	10+69.3-D	639,547.4	869,257.0	Tunnel	"
77	1255			Mott	2180.1	13+92.1	22+13.0-D	640,218.4	867,982.5	Tunnel	"
78	1253			Mott	3130.9	22+90.0	32+08.6-D	640,745.6	866,749.7	Tunnel	"
79	Lost	108	38	Mathews	2117.9	17+75.4	22+18.8-D	640,062.9	867,632.1	Tunnel	"
80	Lost	106	3	Mathews	2084.6	21+13.9	24+80.6-D	640,158.6	867,215.0	Tunnel	"
81	1235	101	3[illegible]	Mathews	2058.0	26+86.7	26+11.8-D	640,037.3	866,640.0	Tunnel	"
82	1235	101	42	Mathews	2062.6	25+58.7	29+42.4-D	640,391.1	866,617.5	Tunnel	"
83	1235	109	27	Mathews	2080.5	22+11.0	28+14.4-D	640,420.8	866,986.8	Tunnel	"
84	1221	109	1	Mathews	2132.4	19+15.3	26+40.3-D	640,386.8	867,328.3	Tunnel	"
85		105	19	Mathews	2192.5	18+12.2	30+25.3-D	640,779.5	867,260.4	Tunnel	"
86		109	22	Mathews	2142.8	21+46.7	32+38.9-D	640,833.2	866,867.1	Tunnel	"
87	1235	102	47	Mathews	2087.9	25+36.4	33+43.8-D	640,764.9	866,469.3	Tunnel	"
88	1228	101	16	Mathews	2054.6			640,588.0	865,998.3	Tunnel	"
89	1227	105	14	Mathews	2096.54	8+45.27	16+03.14-U	636,983.7	870.079.7	Tunnel	"
91	1222	106	16	Mathews	2101.63	6+63.2	13+63.6-U	637,277.5	870,144.5	Tunnel	"

*Log Books in Box No. 22

TABULATION AND INDEX OF DRILL HOLE LOGS FOR FOUNDATION INVESTIGATIONS FOR FORT PECK DAM - Contd

Hole No.	Field Book Number	*Log Book Number	*Log Book Page	Contractor	Ground Elevation	Station	Range	Latitude	Departure	Designation	File Location
92	1243	Mott		Mott	22[illegible].4	1+53.4	8+39.2-U	637,967.4	870,387.3	Tunnel	Box 36
93	1221	108	43	Mathews	2089.35	9+34.4	15+03.0-U	637,037.2	869,956.8	Tunnel	"
94	1225-1227	103	17	Mathews	20[illegible].48	10+47.7	16+43.2-U	636,862.4	869,912.7	Tunnel	"
95	1250	Mott		Mott	2[illegible].6	6+26.0	20+16.3-D	640,361.2	868,760.4	Tunnel	"
96		105	1	Mathews	2224.12	11+83.9	25+70.9-D	640,628.6	868,016.8	Tunnel	"
97	1227	104	11	Mathews	2164.5	19+12.4	28+17.1-D	640,548.6	867,256.7	Tunnel	"
Hole No. 98 through 114											
115	1259			Diamond	2053.87	90+39.4	79+67.1-D	642,233.7	858,626.8	Borrow D	"
116	1259			Diamond	2055.5	80+39.4	79+67.1-D	642,653.2	859,534.6	Borrow D	"
117	1259			Diamond	2047.9	70+38.7	79+66.9-D	643,072.8	860,443.0	Borrow D	"
118	1259			Diamond	2049.1	60+38.8	79+66.9-D	643,492.3	861,350.7	Borrow D	"
119	1150			Diamond	2026.4	50+38.7	79+67.0-D	643,911.9	862,258.5	Borrow D	Box 35
120	1150			Diamond	2035.1	40+68.0	79+58.2-D	644,311.1	863,143.3	Borrow D	"
121	1142			Diamond	2056.5	30+68.0	79+58.3-D	644,730.7	864,051.0	Borrow D	"
122	1142			Diamond	2054.1	35+68.1	73+58.4-D	643,976.3	863,848.8	Borrow D	"
123	1235	101	1	Mathews	2047.0	76+17.2	0+62.5-D	635,654.9	863,233.7	Axis	Box 36
124	1235	101	5	Mathews	2049.3	81+67.5	0+64.6-D	635,425.9	862,733.3	Axis	"
125	1142			Diamond	2038.1	45+68.1	73+58.1-D	643,556.7	862,941.1	Borrow D	Box 35
126	1142			Diamond	2033.4	55+13.7	73+66.9-D	643,167.9	862,079.0	Borrow D	"
127	1259			Diamond	2048.7	65+38.6	73+66.9-D	642,737.9	861,148.6	Borrow D	Box 36
128	1259			Diamond	2055.4	79+09.4	73+67.2-D	642,163.2	859,904.3	Borrow D	"
129	1259			Diamond	2055.8	85+39.4	73+67.1-D	641,893.8	859,332.4	Borrow D	"
130	1259			Diamond	2054.6	95+39.4	73+67.0-D	641,479.3	858,424.7	Borrow D	"
131	1259			Diamond	2055.7	90+39.8	67+67.2-D	641,144.4	859,129.8	Borrow D	"
132	1259			Diamond	2056.0	80+38.9	67+67.0-D	641,564.0	860,038.5	Borrow D	"
133	1259			Diamond	2047.5	70+38.7	67+66.9-D	641,983.5	860,946.4	Borrow D	"
134	1259			Diamond	2049.7	60+88.6	67+67.0-D	642,382.1	861,808.8	Borrow D	"
135	1143			Diamond	2034.3	50+63.1	67+58.2-D	642,802.3	862,738.9	Borrow D	Box 35
136	1143			Diamond	2045.0	40+68.1	67+58.1-D	643,221.8	863,646.6	Borrow D	"
137	1142			Diamond	2054.2	38+68.1	61+58.2-D	642,761.1	864,079.8	Borrow D	"
138	1152			Diamond	2057.8	191+12.4	34+48.5-U	627,645.6	854,271.8	L Abut	"
139	1152			Diamond	2055.9	181+68.6	34+40.3-U	628,049.0	855,125.0	L Abut	"
140	1152			Diamond	2057.1	172+28.6	34+40.0-U	628,443.5	855,978.3	L Abut	"
141	1152			Diamond	2055.4	162+88.6	34+39.8-U	628,837.9	856,831.5	L Abut	"
142	1152			Diamond	2054.4	153+48.7	34+39.5-U	629,232.7	857,684.5	L Abut	"
143	1152			Diamond	2045.4	144+08.7	34+39.4-U	629,627.1	858,537.7	L Abut	"
144	1152			Diamond	2058.0	186+38.5	39+40.8-U	627,397.6	854,908.5	L Abut	"
145	1223	102	19	Mathews	2073.0	16+39.5	36+62.6-U	634,781.0	870,[illegible].7	Borrow U	Box 36
146	1223	102	17	Mathews	2070.8	25+09.5	36+62.6-U	634,416.0	869,[illegible].9	Borrow U	"
147	1223	102	15	Mathews	2066.1	34+64.5	36+62.6-U	634,025.4	868,566.0	Borrow U	"
148	1223	102	11	Mathews	2064.5	45+14.5	36+62.5-U	633,575.0	867,612.8	Borrow U	"
149	1226	110	52	Mathews	Top of Toe 2021.1	54+84.6	36+62.5-U	633,163.1	866,732.2	Borrow U	"
150	1223	101	35	Mathews	2046.5	65+86.7	36+67.6-U	632,701.1	865,733.9	Borrow U	"
151	1223	101	23	Mathews	2046.6	75+87.2	36+67.5-U	632,281.6	864,825.7	Borrow U	"
151A	1230	111	1	Gov't Labor						Borrow U	"
152	1223-1053	101	13	Mathews	2045.9	85+37.3	36+67.5-U	631,883.0	863,963.3	Borrow U	"
153	1223	101	25	Mathews	2051.1	95+27.2	36+67.7-U	631,467.6	863,064.7	Borrow U	"
154	1223	102	1	Mathews	2054.13	105+67.1	26+67.7-U	631,031.3	862,120.7	Borrow U	"
155	1223	102	7	Mathews	2055.0	101+47.1	26+82.6-U	632,101.7	862,088.7	Borrow U	"
156	1223	102	5	Mathews	2051.7	90+72.1	26+82.4-U	632,552.7	863,064.5	Borrow U	"
157	1223	101	37	Mathews	2051.6	80+87.2	26+82.5-U	632,965.9	863,958.6	Borrow U	"
158	1223	101	45	Mathews	2045.8	70+42.1	26+82.5-U	633,402.2	864,902.7	Borrow U	"
159	1226	102	32	Mathews	2060.6	50+44.5	26+82.6-U	634,242.2	866,720.6	Borrow U	"
160	1226	102	30	Mathews	2062.2	40+04.5	26+82.6-U	634,678.5	867,664.7	Borrow U	"
161	1226	102	28	Mathews	2062.9	30+54.5	26+82.6-U	635,077.0	868,527.1	Borrow U	"
162	1226	102	26	Mathews	2064.2	21+04.4	26+82.7-U	635,475.5	869,389.5	Borrow U	"
163	1226	103	11	Mathews	2063.77	16+19.5	17+17.6-U	636,555.0	869,424.9	Borrow U	"
164	1226	102	40	Mathews	2059.8	26+04.5	17+17.7-U	636,141.8	868,530.8	Borrow U	"
165	1226	102	38	Mathews	2060.1	35+79.5	17+17.7-U	635,732.8	867,645.7	Borrow U	"
166	1226	102	36	Mathews	2056.1	46+19.6	17+17.6-U	635,296.5	866,701.6	Borrow U	"
167	1226	102	34	Mathews	2052.5	55+69.6	17+17.7-U	634,898.0	865,839.2	Borrow U	"
168	1223	102	3	Mathews	2040.6	65+94.7	17+17.6-U	634,468.0	864,908.7	Borrow U	"
169	1223	101	47	Mathews	2051.3	76+47.2	17+17.5-U	634,026.5	863,953.2	Borrow U	"
170	1223	101	49	Mathews	2050.2	85+97.2	17+17.7-U	633,627.9	863,090.9	Borrow U	"
171	1224	103	9	Mathews	2062.7	84+64.0	26+40.0-D	637,639.4	861,383.8	Berm D	"
172	1223	101	51	Mathews	2046.0	74+53.9	26+39.9-D	638,063.0	862,300.7	Berm D	"
173	1226	103	13	Mathews	2042.02	54+53.9	26+39.6-D	638,901.7	864,116.4	Berm D	"
174	1226	103	41	Mathews	2051.15	45+43.8	26+39.4-D	639,283.3	864,942.6	Berm D	"
175	1226	103	15	Mathews	2051.19	35+13.9	26+39.2-D	639,715.2	865,877.6	Berm D	"
176	1226	103	43	Mathews	2065.12	25+28.9	26+39.0-D	640,128.3	866,771.8	Berm D	"
177	1226	110	54	Mathews	2065.3	30+18.7	35+99.0-D	640,794.3	865,924.4	Borrow D	"
178	1226	103	45	Mathews	2050.07	39+63.7	35+99.3-D	640,398.0	865,066.5	Borrow D	"
179	1226	104	3	Mathews	2045.09	49+23.8	35+99.3-D	639,995.4	864,195.0	Borrow D	"
180	1226	104	5	Mathews	2041.41	57+48.8	35+99.5-D	639,649.4	863,446.0	Borrow D	"
181	1223	102	9	Mathews	2046.8	69+33.8	35+99.7-D	639,152.5	862,370.2	Borrow D	"
182	1224	103	5	Mathews	2057.25	79+38.8	36+00.0-D	638,731.1	861,457.8	Borrow D	"
183	1224	103	7	Mathews	2060.73	88+78.9	36+00.1-D	638,336.9	860,604.4	Borrow D	"
184	1224	103	1	Mathews	2057.55	94+88.7	45+75.2-D	638,966.2	859,641.8	Borrow D	"
185	1224	103	3	Mathews	2057.71	85+13.7	45+75.1-D	639,375.1	860,526.9	Borrow D	"
186	1224-1259	104	9	Mathews	2046.65	75+13.7	45+74.8-D	639,794.4	861,434.7	Borrow D	"
187	1223	102	13	Mathews	2044.1	65+33.8	45+74.6-D	640,205.3	862,324.4	Borrow D	"

*Log Books in Box No. 22

TABULATION AND INDEX OF DRILL HOLE LOGS FOR FOUNDATION INVESTIGATIONS FOR FORT PECK DAM - Contd

Hole No.	Field Book Number	*Log Book Number	*Log Book Page	Contractor	Ground Elevation	Station	Range	Latitude	Departure	Designation	File Location
188	1226	103	47	Mathews	2040.71	62+28.4	30+82.3-D	640,645.6	863,277.6	Borrow D	Box 36
189	1226	104	1	Mathews	2043.92	45+78.7	45+74.3-D	641,025.2	864,099.3	Borrow D	"
190	1226	104	7	Mathews	2049.73	35+68.6	45+74.3-D	641,448.8	865,016.2	Borrow D	"
191		105	47	Mathews	2118.72	9+31.0	12+43.4-U	637,274.3	869,851.0	Tunnel	"
192	1244	Mott		Mott	2250.7	4+54.7	8+66.6-U	637,816.3	870,125.3	Tunnel	"
194	1246			Mott	2278.1	3+10.7	5+41.4-D	639,154.7	869,665.3	Tunnel	"
198	1221-1234	105	36	Mathews	2097.8	19+56.3	24+77.4-D	640,221.9	867,359.4	Tunnel	"
199	1245	Mott		Mott	2133.7	5+26.8	5+56.5-U	638,067.3	869,929.8	Tunnel	"
200	1251			Mott	2199.6	5+37.0	1+14.8-D	638,672.5	869,638.9	Tunnel	"
201	1203	4	32	Longyear	2049.1	84+82.7	10+26.0-U	634,303.7	862,904.7	Berm U	"
202	1203	4	35	Longyear	2065.6	87+23.3	10+04.8-U	634,222.0	852,677.4	Berm U	"
203	1247			Mott	2229.6	-1+69.7	9+57.8-U	637,995.3	870,730.4	Tunnel	"
204	1252			Mott	2194.9	9+68.9	15+61.8-D	639,804.9	868,639.8	Tunnel	"
205	1152			Diamond	2058.7	176+98.4	39+40.5-U	627,792.1	855,761.8	Borrow Aux	Box 35
206	1152			Diamond	2055.4	167+58.3	39+40.5-U	628,186.5	856,615.0	Borrow Aux	"
207	1152			Diamond	2054.5	158+18.3	39+40.4-U	628,581.0	857,468.2	Borrow Aux	"
208	1152			Diamond	2043.9	148+98.37	39+40.10-U	628,967.0	858,303.3	Borrow Aux	"
209	1152			Diamond	2047.2	154+26.2	44+40.5-U	628,291.3	858,034.1	Borrow Aux	"
210	1152			Diamond	2051.5	162+88.2	44+40.8-U	627,929.6	857,251.7	Borrow Aux	"
211	1152			Diamond	2055.3	172+28.2	44+40.98-U	627,535.1	856,398.5	Borrow Aux	"
212	1152			Diamond	2059.7	181+68.2	44+40.9-U	627,140.7	855,545.2	Borrow Aux	"
213	1152			Diamond	2059.2	191+08.2	44+41.2-U	626,746.2	854,692.0	Borrow Aux	"
219	1203	5	1	Longyear	2064.4	89+13.3	33+98.9-D	638,139.9	860,657.6	Borrow D	Box 36
220	1203	4	4	Longyear	2075.4	90+14.8	32+50.2-D	637,962.3	860,627.8	Borrow D	"
221	1249			Mott	2185.3	7+44.8	6+35.0-D	639,057.5	869,232.0	Tunnel	"
222	1246			Mott	2154.7	9+93.9	12+66.5-D	639,526.2	868,741.0	Tunnel	"
223	1222-1254			Mott	2166.5	12+43.0	19+14.2-D	640,009.8	868,243.2	Tunnel	"
224	1222-1230	106	31	Mathews	2157.69	16+23.1	24+34.1-D	640,322.1	867,680.1	Tunnel	"
225	1227	103	23	Mathews	2071.86	23+67.9	28+86.0-D	640,420.1	866,814.4	Tunnel	"
226	1250			Mott	2212.5	3+50.4	2+40.4-U	638,428.4	869,957.3	Tunnel	"
227	1248			Mott	2232.7	5+62.1	4+50.4-D	638,966.6	869,475.3	Tunnel	"
228	1244			Mott	2205.8	8+28.2	11+83.3-D	639,520.3	868,926.3	Tunnel	"
229	1222	106	22	Mathews	2215.36	12+93.1	23+15.6-D	640,353.2	868,029.3	Tunnel	"
230	1227	109	12	Mathews	2066.39	23+39.4	25+48.7-D	640,125.8	866,981.7	Tunnel	"
231	1241			Mott	2191.9	2+46.3	4+94.7-U	638,241.1	870,158.4	Tunnel	"
232	1256			Mott	2274.4	5+01.2	6+86.8-D	639,206.8	869,431.4	Tunnel	"
233	1257			Mott	2253.8	7+28.6	16+06.6-D	639,946.4	868,839.1	Tunnel	"
234	1242			Mott	2206.7	9+58.3	18+55.9-D	640,076.3	868,526.0	Tunnel	"
235	1222-1230	108	28	Mathews	2201.8	9+55.2	23+18.8-D	640,497.8	868,334.6	Tunnel	"
236	1221	106	8	Mathews	2161.7	17+02.2	28+35.9-D	640,654.0	867,439.8	Tunnel	"
237	1227	104	36	Mathews	2102.0	23+53.2	31+06.9-D	640,626.8	866,735.0	Tunnel	"
238	1243			Mott	2185.1	4+78.1	10+78.4-U	637,614.1	870,192.9	Tunnel	"
239	1221	108	46	Mathews	2076.8	12+32.0	15+14.9-U	636,901.6	869,691.6	Tunnel	"
240	1227	103	36	Mathews	2073.19	11+78.2	18+28.3-U	636,639.6	869,871.9	Tunnel	"
241	1227	103	29	Mathews	2079.9	11+49.4	20+91.7-U	636,412.6	870,008.6	Tunnel	"
242	1225	109	7	Mathews	2091.16	10+35.7	24+14.6-U	636,167.2	870,247.2	Tunnel	"
243	1241	Mott		Mott	2125.2	8+74.6	20+75.0-U	636,543.0	870,251.0	Tunnel	"
244	1222	106	39	Mathews	2091.49	9+98.7	20+35.0-U	636,527.3	870,121.6	Tunnel	"
245	1232	109	46	Mathews	2057.1	88+39.0	41+00.1-D	638,807.6	860,430.8	Borrow D	"
246	1229	107	46	Mathews	2048.8	77+24.1	41+00.0-D	639,275.2	861,443.0	Borrow D	"
247	1234	108	13	Mathews	2044.82	66+24.1	40+99.8-D	639,736.5	862,441.6	Borrow D	"
248	1237	110	22	Mathews	2040.95	56+98.9	40+99.7-D	640,124.4	863,281.3	Borrow D	"
249	1237	111	16	Mathews	2050.45	37+91.6	41+06.9-D	640,931.1	865,009.8	Borrow D	"
250	1237	110	37	Mathews	2044.75	40+75.2	50+78.6-D	641,694.1	864,344.6	Borrow D	"
251	1237	110	32	Mathews	2044.54	50+75.3	50+78.6-D	641,274.6	863,436.9	Borrow D	"
252	1232	104	43	Mathews	2044.6	62+25.3	50+59.7-D	640,775.1	862,400.9	Borrow D	"
253	1232	109	42	Mathews	2050.5	69+47.0	50+43.4-D	640,457.6	861,752.6	Borrow D	"
254	1234	108	7	Mathews	2057.47	78+98.9	50+50.0-D	640,064.2	860,885.7	Borrow D	"
255	1234	108	18	Mathews	2055.87	89+29.0	50+50.1-D	639,632.2	859,950.7	Borrow D	"
256	1153	111	12	Mathews	2075.36	19+70.9	41+60.9-U	634,189.8	870,130.9	Borrow U	"
257	1237	111	25	Mathews	2072.21	29+24.7	41+83.1-U	633,769.3	869,274.2	Borrow U	"
258	1237	111	19	Mathews	2069.61	38+73.3	41+68.2-U	633,384.9	868,406.9	Borrow U	"
259	1236	110	44	Mathews	2064.71	49+01.9	41+73.2-U	632,948.9	867,475.4	Borrow U	"
260	1229	107	27	Mathews	2049.77	70+22.3	41+67.7-U	632,064.6	865,548.3	Borrow U	"
261	1231	107	18	Mathews	2047.62	81+47.0	41+67.5-U	631,592.7	864,527.1	Borrow U	"
262	1231	107	1	Mathews	2053.33	98+77.0	31+67.5-U	631,774.8	862,537.2	Borrow U	"
263	1229	107	42	Mathews	2051.1	88+97.2	31+67.6-U	632,185.9	863,426.8	Borrow U	"
264	1231	107	9	Mathews	2046.4	78+47.1	31+67.5-U	632,626.4	864,380.0	Borrow U	"
265	1231	106	44	Mathews	2046.2	70+82.1	31+67.6-U	632,947.3	865,074.5	Borrow U	"
266	1236	110	26	Mathews	2062.9	47+77.4	31+93.4-U	633,890.7	867,177.4	Borrow U	"
267	1236	110	16	Mathews	2064.7	38+26.4	31+76.9-U	634,304.6	868,033.8	Borrow U	"
268	1236	110	5	Mathews	2065.9	28+55.2	31+48.6-U	634,737.7	868,903.5	Borrow U	"
269	1236	110	11	Mathews	2067.36	21+59.4	31+63.7-U	635,015.7	869,541.3	Borrow U	"
270	1229	107	32	Mathews	2051.02	90+77.0	41+67.5-U	631,202.6	863,682.9	Borrow U	"
271	1229	107	23	Mathews	2048.13	100+77.3	41+67.6-U	630,793.1	862,775.1	Borrow U	"
272	1231	107	5	Mathews	2055.8	113+97.3	41+67.5-U	630,229.4	861,576.8	Borrow U	"
273	1232	110	1	Mathews	2035.56	60+91.8	30+28.4-U	633,489.1	865,915.0	Borrow U	"
274	1231	107	14	Mathews	2052.04	89+27.4	20+08.5-U	633,225.4	862,913.1	Borrow U	"

*Log Books in Box No. 22

Army CE Riverdale, ND

TABULATION AND INDEX OF DRILL HOLE LOGS FOR FOUNDATION INVESTIGATIONS FOR FORT PECK DAM - Contd

Hole No.	Field Book Number	*Log Book Number	*Log Book Page	Contractor	Ground Elevation	Station	Range	Latitude	Departure	Designation	File Location
275	1229	107	37	Mathews	2050.67	76+87.5	21+19.4-U	633,644.8	864,085.2	Borrow U	Box 36
276	1232	104	48	Mathews	2035.4	64+01.3	21+19.2-U	634,184.5	865,252.7	Borrow U	"
277	1232	109	35	Mathews	2051.91	52+44.5	21+46.6-U	634,644.9	866,314.2	Borrow U	"
278	1232	109	36A	Mathews	2059.9	40+96.4	20+77.7-U	635,189.1	867,327.5	Borrow U	"
279	1234	108		Mathews	2061.2	30+09.6	20+87.9-U	635,635.8	868,318.4	Borrow U	"
280	1230	108	25	Mathews	2035.64	61+80.4	27+48.8-D	638,696.2	863,411.1	Berm U	"
281	1234	108	1	Mathews	2048.1	69+08.4	32+21.4-D	638,819.8	862,552.0	Borrow D	"
282	1237	111	7	Mathews	2050.60	41+13.7	31+25.3-D	639,904.9	865,129.2	Borrow D	"
283	1236	110	41	Mathews	2051.85	32+05.9	31+24.5-D	640,285.0	865,953.6	Borrow D	"
283A	1230	108	22	Mathews	2030.46	58+46.5	0+63-D	636,398.2	864,840.9	Axis	"
284				Diamond	2042.8	45+68.2	61+58.2-D	642,467.4	863,[illegible]4.4	Borrow D	"
285				Diamond	2034.6	52+69.6	63+08.8-D	642,309.8	862,744.5	Borrow D	"
286	1259			Diamond	2049.5	65+40.0	61+67.5-D	641,648.6	861,650.5	Borrow D	"
287	1150			Diamond	2047.7	75+40.0	61+67.5-D	641,229.1	860,742.8	Borrow D	Box 35
288	1150			Diamond	2055.5	85+40.0	61+67.5-D	640,809.6	859,835.0	Borrow D	"
289	1150			Diamond	2056.5	93+89.9	61+67.3-D	640,452.9	859,063.6	Borrow D	"
290	1143			Diamond	2055.6	90+40.0	55+67.3-D	640,055.1	859,632.9	Borrow D	"
291	1138			Diamond	2057.7	80+40.0	55+67.5-D	640,474.7	860,540.6	Borrow D	"
292	1134			Diamond	2049.4	70+40.1	55+67.5-D	640,894.2	861,448.3	Borrow D	"
293	1259			Diamond	2045.7	60+40.0	55+67.6-D	641,313.8	862,356.1	Borrow D	"
294	1134			Diamond	2041.2	50+68.0	55+58.2-D	641,713.0	863,242.3	Borrow D	"
295	1134			Diamond	2043.8	45+18.1	55+58.2-D	641,943.7	863,741.5	Borrow D	"
296	1134			Diamond	2058.5	35+18.2	55+58.2-D	642,363.2	864,649.2	Borrow D	"
297	1138			Diamond	2049.5	38+30.9	47+70.4-D	641,516.9	864,695.8	Borrow D	"
298	1138			Diamond	2044.7	48+30.8	47+71.9-D	641,098.8	863,787.5	Borrow D	"
299	1138			Diamond	2035.8	58+32.53	47+68.98-D	640,675.9	862,879.4	Borrow D	"
300	1139			Diamond	2050.1	68+32.5	47+68.9-D	640,256.4	861,971.7	Borrow D	"
301	1135			Diamond	2047.1	78+32.6	47+68.4-D	639,836.4	861,064.1	Borrow D	"
302	1150			Diamond	2056.6	88+32.5	47+68.4-D	639,416.9	860,156.4	Borrow D	"
303	1138			Diamond	2049.2	95+87.6	47+68.3-D	639,100.1	859,471.0	Borrow D	"
304	1138			Diamond	2056.9	90+72.6	42+68.4-D	638,862.3	860,148.2	Borrow D	"
305	1139			Diamond	2057.3	80+72.5	42+68.5-D	639,281.9	861,056.0	Borrow D	"
306	1139			Diamond	2047.8	70+72.48	42+68.7-D	639,701.6	861,963.7	Borrow D	"
307	1139			Diamond	2035.5	60+72.5	42+68.7-D	640,121.1	862,871.4	Borrow D	"
308	1139			Diamond	2039.6	50+72.5	42+69.0-D	640,540.9	863,779.1	Borrow D	"
309	1139			Diamond	2050.2	40+81.6	42+70.82-D	640,958.2	864,677.8	Borrow D	"
310	1136			Diamond	2050.0	34+72.74	37+69.01-D	640,758.1	865,441.0	Borrow D	"
311	1135			Diamond	2045.0	44+72.78	37+70.46-D	640,339.9	864,532.6	Borrow D	"
312	1135			Diamond	2039.7	54+72.5	37+69.0-D	639,919.2	863,625.7	Borrow D	"
313	1136			Diamond	2047.6	64+72.2	37+68.8-D	639,499.6	862,718.3	Borrow D	"
314	1151			Diamond	2047.8	74+72.2	37+68.7-D	639,080.1	861,810.6	Borrow D	"
315	1151			Diamond	2057.3	84+72.3	37+68.7-D	638,660.5	860,902.8	Borrow D	"
		Field Book Page No.									
316	1131	16		Diamond	2059.3	80+85.11	20+61.70-D	637,273.4	861,970.3	Found D	"
317	1131	26		Diamond	2046.6	71+10.04	20+61.77-D	637,682.5	862,355.4	Found D	"
318	1137	16		Diamond	2041.4	61+35.05	20+61.87-D	638,091.6	863,740.4	Found D	"
319	1137	30		Diamond	2034.2	52+08.19	20+62.30-D	638,480.8	864,581.6	Found D	"
320	1131	1		Diamond	2051.5	43+08.15	20+62.34-D	638,858.4	865,398.6	Found D	"
321	1137	4		Diamond	2051.2	34+08.10	20+62.38-D	639,236.0	866,215.6	Found D	"
322	1125	14		Diamond	2058.7	25+08.15	20+62.46-D	639,613.6	867,032.5	Found D	"
323	1124	24		Diamond	2075.5	20+58.12	16+37.47-D	639,416.6	867,619.3	Found D	"
324	1124	18		Diamond	2056.3	29+58.07	16+37.39-D	639,039.0	866,802.4	Found D	"
325	1132	33		Diamond	2052.2	38+58.12	16+37.35-D	638,661.4	865,985.4	Found D	"
326	1130	2		Diamond	2052.5	47+58.15	16+37.31-D	638,283.8	865,168.4	Found D	"
327	1125	43		Diamond	2032.1	56+51.00	16+33.28-D	637,905.6	864,359.6	Found D	"
328	1130	14		Diamond	2040.5	66+24.30	16+36.81-D	637,500.5	863,474.6	Found D	"
329	1125	33		Diamond	2048.2	76+10.06	16+36.72-D	637,086.9	862,579.8	Found D	"
330	1125	21		Diamond	2061.2	80+85.05	12+11.77-D	636,501.9	862,326.9	Found D	"
331	1132	4		Diamond	2035.3	71+35.12	12+11.78-D	636,900.4	863,189.2	Found D	"
332	1132	48		Diamond	2040.7	61+44.29	12+11.84-D	637,316.1	864,088.6	Found D	"
333	1124	49		Diamond	2031.5	52+48.12	12+12.34-D	637,692.5	864,901.9	Found D	"
334	1132	20		Diamond	2052.6	43+08.12	12+12.31-D	638,086.8	865,755.2	Found D	"
335	1125	4		Diamond	2056.9	34+08.08	12+12.35-D	638,464.4	866,572.2	Found D	"
336	1124	10		Diamond	2057.4	25+08.14	12+12.44-D	638,842.0	867,389.1	Found D	"
337	1124	4		Diamond	2075.7	16+69.05	11+60.68-D	639,147.0	868,172.5	Found D	"
338	1127	4		Diamond	2058.9	20+58.10	7+87.45-D	638,645.0	867,975.9	Found D	"
339	1127	10		Diamond	2057.2	29+57.63	7+88.28-D	638,268.4	867,159.0	Found D	"
340	1115	5		Diamond	2053.4	38+58.09	7+87.33-D	637,889.8	866,342.0	Found D	"
341	1112	3		Diamond	2052.8	47+58.09	7+87.38-D	637,512.3	865,525.0	Found D	"
342	1124	33		Diamond	2033.2	56+98.03	7+87.28-D	637,117.9	864,671.8	Found D	"
343	1112	16		Diamond	2042.7	66+23.51	7+86.54-D	636,729.0	863,832.0	Found D	"
344	1112	32		Diamond	2048.9	76+10.00	7+86.79-D	636,315.4	862,936.4	Found D	"
345	1101	6		Diamond	2048.2	80+79.91	3+61.6-D	635,732.3	862,688.2	Found D	Box 34
346	1101	15		Diamond	2035.4	71+31.62	3+58.07-D	636,126.9	863,550.5	Found D	"
347	1101	61		Diamond	2042.1	61+43.6	3+61.62-D	636,544.6	864,445.9	Found D	"
348	1109	20		Diamond	2050.8	51+95.03	3+62.26-D	636,943.1	865,306.7	Found D	Box 35
349	1123	4		Diamond	2054.9	42+95.07	3+62.34-D	637,320.7	866,123.6	Found D	"
350	1123	19		Diamond	2057.6	33+95.04	3+62.38-D	637,698.3	866,940.6	Found D	"
351	1123	32		Diamond	2058.5	24+95.09	3+62.47-D	638,075.9	867,757.5	Found D	"

*Log Books in Box No. 22

TABULATION AND INDEX OF DRILL HOLE LOGS FOR FOUNDATION INVESTIGATIONS FOR FORT PECK DAM - Contd

Hole No.	Field Book Number	Field Book Page No.	Contractor	Ground Elevation	Station	Range	Latitude	Departure	Designation	File
352	1103	67	Diamond	2064.6	15+95.05	3+62.51-D	638,453.5	868,574.5	Found D	Box 34
353	1105	36	Diamond	2072.8	12+95.10	0+37.52-U	638,216.2	869,014.6	Axis	Box 35
354	1105	28	Diamond	2061.2	15+95.05	0+37.49-U	638,090.4	868,742.3	Axis	"
355	1133	20	Diamond	2059.0	18+95.04	0+37.54-U	637,964.5	868,470.0	Axis	"
356	1118	18	Diamond	2058.3	21+95.04	0+37.6-U	637,838.6	868,197.7	Axis	"
357	1107	20	Diamond	2058.0	24+95.0	0+37.58-U	637,712.8	867,925.4	Axis	"
358	1108	23	Diamond	2058.0	27+95.08	0+37.59-U	637,586.9	867,653.0	Axis	"
359	1110	25	Diamond	2057.5	30+95.04	0+37.56-U	637,461.1	867,380.7	Axis	"
360	1116	24	Diamond	2057.7	33+95.03	0+37.62-U	637,335.2	867,108.4	Axis	"
361	1104	51	Diamond	2057.8	36+95.04	0+37.67-U	637,209.3	866,836.1	Axis	"
362	1118	4	Diamond	2054.2	39+94.99	0+37.64-U	637,083.5	866,563.8	Axis	"
363	1133	2	Diamond	2055.0	42+95.07	0+37.66-U	636,957.6	865,291.4	Axis	"
364	1105	14	Diamond	2055.4	45+95.03	0+37.62-U	636,831.8	866,019.1	Axis	"
365	1104	35	Diamond	2055.9	48+95.03	0+37.68-U	636,705.9	865,746.8	Axis	"
366	1107	1	Diamond	2053.4	51+95.02	0+37.73-U	636,580.0	865,474.5	Axis	"
367	1109	1	Diamond	2056.0	54+96.6	0+41.3-U	636,454.2	865,202.2	Axis	"
368	1107	32	Diamond	2029.3	57+95.06	0+37.72-U	636,328.3	864,929.8	Axis	"
369	1116	39	Diamond	2035.5	60+45.47	0+41.31-U	636,220.0	864,704.0	Axis	"
370	1116	2	Diamond	2042.7	64+68.61	0+41.08-U	636,042.7	864,319.8	Axis	"
371	1108	2	Diamond	2042.5	67+96.21	0+39.84-U	635,906.4	864,021.9	Axis	"
372	1110	2	Diamond	2035.3	71+44.22	0+38.2-U	635,761.9	863,705.3	Axis	"
373	1105	1	Diamond	2047.2	72+94.24	0+38.16-U	635,699.0	863,569.1	Axis	"
374	1104	1	Diamond	2047.6	75+94.24	0+38.23-U	635,573.1	863,296.8	Axis	"
375	1103	2	Diamond	2049.9	78+94.19	0+38.19-U	635,447.3	863,024.5	Axis	Box 34
376	1103-1153	13	Diamond	2052.2	81+94.0	0+38.33-U	635,321.4	862,752.4	Axis	34 & 35
377	1103-1153	23	Diamond	2071.5	84+94.28	0+38.26-U	635,195.5	862,479.8	Axis	34 & 35
378	1113	3	Diamond	2216.2	108+79.4	0+44.42-D	634,270.0	860,280.0	Abutment	Box 35
379	1111	108	Diamond	2219.6	114+77.22	1+33.4-D	634,100.0	859,700.0	Abutment	"
380	1111	86	Diamond	2227.1	126+37.84	4+82.48-D	633,930.0	858,500.0	"	"
381	1111	4	Diamond	2228.5	132+23.0	7+41.9-D	633,920.0	857,860.0	"	"
382	1111	63	Diamond	2224.5	137+90.3	10+59.1-D	633,970.0	857,212.0	"	-
383	1113	23	Diamond	2219.3	147+89.0	18+18.1-D	634,240.0	855,987.0	"	"
384	1113	50	Diamond	2222.2	153+21.1	22+73.3-D	634,430.0	855,313.0	"	"
385	1102	1	Diamond	2223.2	158+90.9	27+61.3-D	634,634.0	854,591.0	"	Box 34
386	1111	46	Diamond	2246.0	170+30.6	37+37.5-D	635,042.0	853,147.0	"	Box 35
387	1102	19	Diamond	2244.1	176+38.5	42+57.5-D	635,259.0	852,377.0	"	Box 34
388	1102	44	Diamond	2263.2	182+46.5	47+77.5-D	635,476.0	851,607.0	"	"
389	1111	23	Diamond	2169.1	113+83.89	12+56.01-D	635,158.2	859,313.8	"	Box 35
390	1121	16	Diamond	2228.7	122+75.16	5+44.38-D	633,150.0	859,260.0	"	"
391	1121	46	Diamond	2231.2	135+14.0	1+97.71-U	632,945.0	857,990.0	Found U	"
392	1106	1	Diamond	2050.5	78+80.0	4+38.4-U	635,090.0	863,205.3	"	"
393	1114	45	Diamond	2042.8	69+19.21	4+38.08-U	635,493.3	864,077.3	"	"
394	1106	49	Diamond	2029.0	59+79.17	4+38.02-U	635,887.7	864,930.6	"	"
395	1106	21	Diamond	2055.6	50+35.02	4+37.65-U	636,284.1	865,787.5	"	"
396	1114	4	Diamond	2054.8	40+94.99	4+37.58-U	636,678.5	866,640.8		"
397	1106	36	Diamond	2058.0	31+54.99	4+37.61-U	637,072.8	867,494.1	"	"
398	1114	25	Diamond	2058.6	22+15.04	4+37.50-U	637,467.2	868,347.3	"	"
399	1114	36	Diamond	2073.3	12+75.04	4+37.53-U	637,861.5	869,200.6	"	"
400	1120	45	Diamond	2060.2	17+45.0	9+37.56-U	637,210.45	868,983.75	"	"
401	1120	37	Diamond	2058.9	26+84.98	9+37.59-U	636,816.1	868,130.50	"	"
402	1106	62	Diamond	2058.6	36+25.01	9+37.66-U	636,421.7	867,277.2	"	"
403	1114	55	Diamond	2055.3	45+65.05	9+37.72-U	636,027.3	866,423.9	"	"
404	1120	22	Diamond	2051.7	55+04.96	9+37.74-U	635,633.0	865,570.7	"	"
405	1120	52	Diamond	2041.6	64+69.45	9+38.52-U	635,227.7	864,695.5	"	"
406	1120	4	Diamond	2047.7	74+09.49	9+38.58-U	634,833.3	863,842.2	"	"
407	1120	11	Diamond	2049.9	83+49.49	9+38.54-U	634,439.0	862,988.9	"	"
408	1260	13	Diamond	2051.0	88+18.97	14+38.85-U	633,787.9	862,772.6	"	Box 36
409	1260	5	Diamond	2049.5	78+79.02	14+38.74-U	634,182.3	863,625.8	"	"
410	1260	37	Diamond	2038.1	69+38.53	14+38.90-U	634,576.7	864,479.6	"	"
411	1260	17	Diamond	2051.3	58+34.95	14+37.74-U	635,040.7	865,480.9	"	"
412	1260	22	Diamond	2051.4	50+34.95	14+37.73-U	635,376.3	866,207.1	"	"
413	1128	46	Diamond	2059.1	40+94.91	14+37.66-U	635,770.70	867,060.40	"	"
414	1128	52	Diamond	2059.5	31+55.01	14+37.65-U	636,165.0	867,913.6	"	"
415	1260	27	Diamond	2059.6	22+14.97	14+37.59-U	636,559.4	868,766.9	"	"
416	1260	33	Diamond	2075.7	12+75.02	14+37.49-U	636,953.8	869,620.1	"	"
417	1128	18	Diamond	2062.78	17+44.95	19+37.57-U	636,302.7	869,403.3	Borrow U	Box 35
418	1128	22	Diamond	2060.4	26+84.99	19+37.64-U	635,908.3	868,550.0	"	"
419	1128	28	Diamond	2060.5	36+24.9	19+37.65-U	635,514.0	867,696.8	"	"
420	1128	34	Diamond	2058.7	45+64.94	19+37.71-U	635,119.6	866,843.5	"	"
421	1128	40	Diamond	2051.9	55+04.98	19+37.78-U	634,725.2	865,990.2	"	"
422	1128	59	Diamond	2038.9	65+94.96	17+17.85-U	634,467.6	864,908.5	"	"
423	1128	13	Diamond	2047.0	74+08.42	19+38.90-U	633,925.7	864,262.8	"	"
424	1128	9	Diamond	2051.7	83+48.46	19+38.95-U	633,531.3	863,409.5	"	"
425	1128	4	Diamond	2052.2	92+88.50	19+39.02-U	633,136.9	862,556.2	"	"
426	1119	16	Diamond	2051.9	97+58.03	24+39.19-U	632,485.9	862,339.8	"	"
427	1119	12	Diamond	2050.3	88+18.00	24+39.12-U	632,880.3	863,193.1	"	"
428	1119	6	Diamond	2051.7	78+77.96	24+39.07-U	633,274.7	864,046.4	"	"
429	1119	2	Diamond	2044.1	69+37.96	24+39.01-U	633,669.0	864,899.7	"	"
430	1119	41	Diamond	2040.3	59+98.01	24+38.90-U	634,063.4	865,752.9	"	"
431	1119	23	Diamond	2059.1	50+34.82	24+37.94-U	634,468.4	866,626.8	"	"
432	1119	27	Diamond	2059.3	40+92.64	20+90.43-U	635,179.1	867,336.3	"	"

TABULATION AND INDEX OF DRILL HOLE LOGS FOR FOUNDATION INVESTIGATIONS FOR FORT PECK DAM - Contd

Hole No.	Field Book Number	Field Book Page No.	Contractor	Ground Elevation	Station	Range	Latitude	Departure	Designation	File
433	1119	32	Diamond	2062.1	31+54.92	24+37.74-U	635,257.2	868,333.2	Borrow U	Box 35
434	1119	36	Diamond	2062.7	22+14.98	24+37.63-U	635,651.6	869,186.4	"	"
435	1119	19	Diamond	2079.0	12+74.99	24+37.66-U	636,045.9	870,039.7	"	"
436	1126	25	Diamond	2067.7	17+44.97	29+37.62-U	635,394.9	869,822.8	"	"
437	1126	29	Diamond	2064.3	26+84.92	29+37.72-U	635,000.5	868,969.6	"	"
438	1126	39	Diamond	2063.5	36+24.96	29+37.79-U	634,606.1	868,116.3	"	"
439	1126	30	Diamond	2062.1	45+64.95	29+37.76-U	634,211.8	867,263.0	"	"
440	1126	21	Diamond	2049.7	55+04.90	29+37.86-U	633,817.4	866,409.8	"	"
441	1126	45	Diamond	2038.0	60+91.67	30+28.81-U	633,488.7	865,915.3	"	"
442	1126	16	Diamond	2046.3	74+07.67	29+39.18-U	633,018.0	864,683.1	"	"
443	1126	13	Diamond	2054.6	92+87.89	29+39.13-U	632,229.3	862,976.3	"	"
444	1126	4	Diamond	2055.9	102+27.93	29+39.19-U	631,834.9	862,123.0	"	"
445	1129	6	Diamond	2056.1	106+97.95	34+39.24-U	631,183.8	861,906.1	"	"
446	1129	3	Diamond	2053.8	97+57.91	34+39.19-U	631,578.2	862,759.4	"	"
447	1129	9	Diamond	2054.1	88+17.87	34+39.12-U	631,972.6	863,612.7	"	"
448	1129	21	Diamond	2047.17	78+77.06	34+39.53-U	632,366.9	864,466.9	"	"
449	1129	15	Diamond	2046.6	69+37.02	34+39.46-U	632,761.3	865,320.2	"	"
450	1129	50	Diamond	2035.0	60+27.1	34+39.4-U	633,143.1	866,146.2	"	"
451	1129	26	Diamond	2063.2	50+34.89	34+37.85-U	633,560.7	867,046.2	"	"
452	1129	31	Diamond	2064.9	40+94.94	34+37.75-U	633,955.1	867,899.4	"	"
453	1129	37	Diamond	2066.9	31+54.90	34+37.69-U	634,349.5	868,752.7	"	"
454	1129	42	Diamond	2069.4	22+14.90	34+37.71-U	634,743.80	869,606.00	"	"
455	1129	46	Diamond	2074.6	17+44.9	39+37.8-U	634,487.0	870,242.4	"	"
456	1122	44	Diamond	2072.6	26+84.9	39+37.8-U	634,092.7	869,389.1	"	"
457	1122	39	Diamond	2068.5	36+24.97	39+37.83-U	633,698.3	868,535.8	"	"
458	1122	31	Diamond	2065.3	45+64.92	39+37.93-U	633,303.90	867,682.60	"	"
459	1122	49	Diamond	2043.2	55+55.51	37+18.66-U	633,087.4	866,691.4	"	"
460	1122	27	Diamond	2046.96	64+66.5	39+39.5-U	632,504.8	865,957.1	"	"
461	1122	22	Diamond	2047.67	74+06.5	39+39.6-U	632,110.4	865,103.8	"	"
462	1122	17	Diamond	2047.5	83+46.5	39+39.7-U	631,716.0	864,250.6	"	"
463	1122	4	Diamond	2055.6	92+87.9	39+39.2-U	631,321.5	863,395.8	"	"
464	1122	13	Diamond	2058.5	102+27.9	39+39.2-U	630,927.1	862,542.6	"	"
465	1122	9	Diamond	2057.1	111+67.9	39+39.2-U	630,532.8	861,689.2	"	"
466	1140	71	Diamond	2058.5	116+39.0	44+39.3-U	629,881.7	861,472.3	"	"
467	1140	63	Diamond	2056.1	106+97.8	44+39.2-U	630,276.1	862,325.7	"	"
468	1140	55	Diamond	2055.4	97+57.8	44+39.2-U	630,670.5	863,179.0	"	"
469	1140	44	Diamond	2048.2	88+17.8	44+39.2-U	631,064.8	864,032.3	"	"
470	1140	25	Diamond	2047.6	79+76.0	44+39.8-U	631,459.4	864,887.5	"	"
471	1141	37	Diamond	2050.2	69+36.0	44+39.7-U	631,853.8	865,740.7	"	"
472	1122	59	Diamond	2034.8	59+96.0	44+39.6-U	632,248.2	866,594.0	"	"
473	1141	4	Diamond	2064.4	48+70.89	41+53.56-U	632,979.8	867,495.3	"	"
474	1141	20	Diamond	2068.5	40+94.90	44+37.92-U	633,047.20	868,319.0	"	"
475	1140	4	Diamond	2073.2	31+55.0	44+37.8-U	633,441.6	869,172.2	"	"
476	1140	15	Diamond	2075.8	22+14.9	44+37.8-U	633,836.0	870,025.5	"	"
477	1134	8	Diamond	2055.1	30+23.6	32+68.3-D	640,492.0	866,058.8	Borrow D	"
478	1134	3	Diamond	2050.2	40+23.6	32+69.8-D	[illegible]	865,250.4	"	"
479	1134	51	Diamond	2045.1	49+23.4	35+99.3-D	639,995.5	864,195.4	"	"
480	1134	44	Diamond	2033.7	64+57.2	25+44.4-D	639,192.6	863,245.5	"	"
481	1134	54	Diamond	2047.0	70+40.5	32+29.9-D	638,815.0	862,428.5	"	"
482	1134	59	Diamond	2058.4	80+22.4	32+68.9-D	638,395.5	861,520.8	"	"
483	1104	30	Diamond	2219.9	111+80.4	0+89.2-D	634,188.4	859,987.9	Abutment	"
484	1104	10	Diamond	2222.2	117+73.1	1+82.8-D	634,020.7	859,410.7	"	"
485	1146	28	Diamond	2056.7	111+66.1	49+39.9-U	629,625.2	862,110.7	Borrow U	"
486	1146	33	Diamond	2053.8	102+26.0	49+39.9-U	630,019.6	862,964.0	"	"
487	1146	21	Diamond	2054.7	92+86.0	49+39.8-U	630,414.0	863,817.3	"	"
488	1146	15	Diamond	2047.7	83+46.1	49+39.8-U	630,808.3	864,670.5	"	"
489	1146	8	Diamond	2052.4	74+06.0	49+39.7-U	631,202.7	865,523.8	"	"
490	1146	3	Diamond	2046.8	64+66.0	49+39.6-U	631,597.1	866,377.1	"	"
491	1144	40	Diamond	2038.4	55+64.8	49+37.6-U	631,977.0	867,194.3	"	"
492	1144	3	Diamond	2066.4	45+64.9	49+37.6-U	632,396.5	868,102.0	"	"
493	1144	8	Diamond	2072.7	36+24.9	49+37.5-U	632,790.9	868,955.2	"	"
494	1144	14	Diamond	2072.6	26+84.9	49+37.5-U	633,185.2	869,808.5	"	"
495	1126	7	Diamond	2053.1	83+47.98	29+39.12-U	632,623.6	863,829.5	"	"
496 through 499 Not Drilled										
500	1010	4	Longyear	2255.4	-56+45.7	6+81.1-D	641,780.2	875,013.7	Spillway C	Box 34
501	1026	41	Longyear	2247.2	-60+06.31	10+09.2-D	642,229.3	875,203.4	"	"
502	1026	1	Longyear	2286.8	-64+18.7	13+13.4-D	642,678.4	878,450.1	"	"
503	1026	24	Longyear	2301.7	-52+81.7	9+70.7-D	641,890.4	874,561.8	"	"
504	1026	53	Longyear	2278.3	-54+97.8	11+77.9-D	642,169.1	874,671.0	"	"
505	1026	10	Longyear	2284.9	-57+15.7	13+85.3-D	642,448.8	874,781.8	"	"
506	1010	8	Longyear	2288.0	-59+31.7	15+92.9-D	642,727.9	874,890.8	"	"
507	1013	1	Longyear	2289.3	-37+92.2	5+56.2-D	643,007.1	875,000.7	"	"
508	1026	47	Longyear	2312.2	-50+75.0	11+87.1-D	642,000.1	874,283.4	"	"
509	1016	2	Longyear	2293.4	-52+91.9	13+94.4-D	642,279.2	874,393.3	"	"
510	1014	28	Longyear	2285.1	-55+08.8	16+01.7-D	642,558.4	874,503.2	"	"
511	1011	10	Longyear	2215.0	-57+25.6	18+08.9-D	642,837.5	874,613.1	"	"
512	1014	35	Longyear	2322.9	-59+42.4	20+16.3-D	643,116.7	874,722.9	"	"
513	1011	1	Longyear	2303.7	-48+68.1	14+03.5-D	642,109.7	874,004.8	"	"
514	1026	34	Longyear	2319.3	-50+84.9	16+10.7-D	642,388.8	874,114.7	"	"
515	1014	42	Longyear	2309.6	-53+01.8	18+18.1-D	642,666.0	874,224.6	"	"
516	1015	1	Longyear	2323.7	-55+18.6	20+25.3-D	642,947.1	874,334.4	"	"

TABULATION AND INDEX OF DRILL HOLE LOGS FOR FOUNDATION INVESTIGATIONS FOR FORT PECK DAM - Contd

Hole No.	Field Book Number	Field Book Page No.	Contractor	Ground Elevation	Station	Range	Latitude	Departure	Designation	File
517	1014	52	Longyear	2329.9	-57+35.5	22+32.7-D	643,226.3	874,444.3	Spillway C	[illegible] 34
518	1010	31	Longyear	2321.6	-46+61.2	16+19.8-D	642,219.3	873,726.2	"	"
519	1026	60	Longyear	2333.0	-48+78.0	18+27.1-D	642,498.4	873,836.1	"	"
520	1026	4	Longyear	2345.2	-50.94.8	20+34.5-D	642,777.6	873,945.9	"	"
521	1026	30	Longyear	2364.5	-53+11.7	22+41.7-D	643,056.7	874,055.8	"	"
522	1015	10	Longyear	2361.5	-55+28.6	24+49.1-D	643,335.9	874,165.7	"	"
523	1010	50	Longyear	2344.4	-44+52.4	18+38.3-D	642,330.0	873,445.0	"	"
524	1018	10	Longyear	2355.2	-46+69.1	20+45.6-D	642,609.1	873,554.8	"	"
525	1010	25	Longyear	2327.0	-48+86.0	22+52.8-D	642,888.2	873,664.7	"	"
526	1011	20	Longyear	2333.8	-51+02.9	24+60.3-D	643,167.5	873,774.6	"	"
527	1010	40	Longyear	2376.2	-53+19.6	26+67.6-D	643,446.6	873,884.4	"	"
528	1010	68	Longyear	2320.6	-42+72.8	24+96.3-D	642,852.0	873,006.0	"	"
529	1010	60	Longyear	2293.0	-44+71.6	26+86.3-D	643,107.9	873,106.7	"	"
530	1013	20	Longyear	2296.5	-46+53.6	28+61.9-D	643,343.6	873,198.3	"	"
531	1018	2	Longyear	2291.2	-48+34.2	30+34.6-D	643,576.2	873,289.8	"	"
532	1010	64	Longyear	2286.2	-36+48.0	30+05.2-D	643,051.9	872,225.3	"	"
533	1010	56	Longyear	2266.4	-39+19.0	32+64.4-D	643,400.8	872,362.6	"	"
534	1016	10	Longyear	2254.9	-40+99.8	34+37.2-D	643,633.5	872,454.2	"	"
535	1013	30	Longyear	2297.3	-42+80.4	36+09.9-D	643,866.1	872,545.7	"	"
536	1015	27	Longyear	2263.2	-32+00.6	35+45.6-D	643,354.7	871,592.5	"	"
537	1017	26	Longyear	2231.5	-34+35.5	37+70.2-D	643,657.1	871,711.5	"	"
538	1015	24	Longyear	2228.7	-29+16.2	32+37.4-D	644,052.5	871,867.1	"	"
539	1017	31	Longyear	2270.3	-23+61.5	41+16.9-D	643,521.3	870,591.1	"	"
540	1019	29	Longyear	2241.6	-28+13.6	44+20.6-D	643,986.6	870,874.2	"	"
541	1019	21	Longyear	2198.7	-31+20.9	47+14.2-D	644,382.1	871,029.9	"	"
542	1019	8	Longyear	2218.7	-20+44.2	47+91.2-D	644,000.3	870,020.2	"	"
543	1027	12	Longyear	2174.0	-22+60.9	49+98.6-D	644,279.5	870,130.0	"	"
544	1027	1	Longyear	2174.6	-24+77.8	52+05.8-D	644,558.6	870,239.9	"	"
545	1020	27	Longyear	2201.7	-13+62.8	59+38.0-D	644,755.5	868,920.6	"	"
546	1020	9	Longyear	2174.2	- 6+71.9	66+60.6-D	645,121.6	867,990.3	"	"
547	1020	3	Longyear	2144.9	0+19.0	73+83.2-D	645,487.7	867,060.0	"	"
548	1014	12	Longyear	2150.8	7+09.9	81+05.9-D	645,853.9	866,129.7	"	"
549	1014	1	Longyear	2113.2	14+00.8	88+28.4-D	646,220.0	865,199.4	"	"
550	1019	2	Longyear	2187.5	-11+23.8	56+85.8-D	644,426.3	868,809.4	"	"
551	1027	7	Longyear	2133.4	- 2+70.6	62+07.2-D	644,541.7	867,816.2	"	"
552	1020	20	Longyear	2101.2	6+08.0	66+84.5-D	644,606.4	866,818.5	"	"
553	1017	8	Longyear	2097.0	15+00.6	71+35.0-D	644,640.9	865,819.5	"	"
554	1017	1	Longyear	2070.6	23+93.3	75+85.5-D	644,675.4	864,819.9	"	"
555	1022	12	Longyear	2347.0	-110+75.2	19+91.9-D	645,247.7	879,392.5	Spillway E	"
556	1024	2	Longyear	2289.1	-113+98.1	17+72.9-D	645,184.4	879,777.5	"	"
557	1023	35	Longyear	2349.0	-117+30.1	15+49.7-D	645,121.0	880,172.5	"	"
558	1024	9	Longyear	2370.2	-111+58.9	21+16.3-D	645,395.8	879,416.3	"	"
559	1023	27	Longyear	2328.1	-113+24.9	20+04.7-D	645,364.1	879,613.8	"	"
560	1014	68	Longyear	2248.8	-108+70.4	1+09.3-D	643,452.8	879,996.3	"	"
561	1018	30	Longyear	2279.5	-109+33.9	10+61.2-D	644,343.6	879,654.6	"	"
562	1012	3	Longyear	2295.3	-114+81.8	18+97.4-D	645,332.5	879,801.2	"	"
563	1019	41	Longyear	2299.1	-120+39.5	27+27.1-D	646,319.6	879,959.4	"	"
564	1017	36	Longyear	2215.8	-125+97.2	35+56.8-D	647,306.7	880,117.6	"	"
565	1018	41	Longyear	2200.4	-131+54.8	6+19.7-U	648,293.8	880,275.7	"	"
566	1018	37	Longyear	2123.0	-137+12.5	52+16.2-D	649,280.9	880,433.9	"	"
567	1027			2089.1	-142+70.1	60+46.0-D	650,268.1	880,592.0	"	"
568	1019	55	Longyear	2081.3	-148+27.8	68+75.7-D	651,255.2	880,750.2	"	"
569	1024	30	Longyear	2328.2	-116+47.8	17+85.8-D	645,300.8	879,998.7	"	"
570	1014	59	Longyear	2234.0	-110+87.9	8+32.0-U	642,689.6	880,588.6	Spillway D	Box 34
571	1011	40	Longyear	2292.6	-118+10.2	1+40.9-U	643,620.0	880,954.4	"	
572	1011	30	Longyear	2338.4	-125+32.4	5+50.2-D	644,550.3	881,320.1	"	"
573	1014	62	Longyear	2285.5	-132+54.3	22+82.5-U	645,480.4	881,685.5	"	"
574	1016	36	Longyear	2197.1	-139+76.1	19+32.3-D	646,410.5	882,050.8	"	"
575	1017	65	Longyear	2143.7	-146+98.0	26+23.3-D	647,340.6	882,416.2	"	"
576	1011	65	Longyear	2120.9	-154+19.7	33+14.3-D	648,270.6	882,781.5	"	"
577	1011	60	Longyear	2151.9	-159+60.9	38+32.5-D	648,968.1	883,055.4	"	"
578	1016	40	Longyear	2077.2	-164+29.8	42+81.5-D	649,572.4	883,292.7	"	"
579	1013	10	Longyear	2222.7	- 63+17.2	5+28.4-D	641,923.2	875,687.3	Spillway C	"
580	1015	17	Longyear	2234.6	- 37+11.9	34+81.0-D	643,510.6	872,083.7	"	"
581	1027		Longyear	2208.3	- 31+24.7	40+95.2-D	643,821.8	871,293.0	"	"
582	1020	33	Longyear	2186.6	- 24+68.3	47+81.7-D	644,169.6	870,409.2	"	"
583	1020	50	Longyear	2161.0	- 20+53.8	52+15.2-D	644,389.2	869,851.1	"	"
584	1015	31	Longyear	2169.1	- 10+86.5	62+27.0-D	644,901.9	868,548.6	"	"
585	1016	13	Longyear	2150.5	- 3+26.5	70+21.8-D	645,304.6	867,525.2	"	"
586	1016	18	Longyear	2161.7	3+64.5	77+44.4-D	645,670.7	866,594.9	"	"
587	1020	39	Longyear	2133.3	9+38.0	83+44.3-D	645,974.7	865,822.6	"	"
588	1013	40	Longyear	2123.9	11+73.0	85+90.1-D	646,099.2	865,506.2	"	"
589	1015	36	Longyear	2099.4	16+77.2	91+17.6-D	646,366.5	864,827.2	"	"
590	1013	34	Longyear	2183.4	- 17+08.2	55+76.6-D	644,572.3	869,385.8	"	"
591	1012	75	Longyear	2264.1	-114+48.9	4+86.5-U	643,154.7	880,771.4	Spillway I	"
592	1012	45	Longyear	2330.1	-121+71.2	2+04.5-D	644,085.0	881,137.2	"	"
593	1012	14	Longyear	2328.8	-128+93.0	8+95.6-D	645,015.1	881,502.5	"	"
594	1011	45	Longyear	2257.8	-136+14.9	15+86.6-D	645,945.2	881,867.9	"	
595	1017	58	Longyear	2169.8			646,875.2	882,233.2	"	"
596	1017	51	Longyear	2132.8			647,805.3	882,598.6	"	"

TABULATION AND INDEX OF DRILL HOLE LOGS FOR FOUNDATION INVESTIGATIONS FOR FORT PECK DAM - Contd

Hole No.	Field Book Number	Field Book Page No.	Contractor	Ground Elevation	Station	Range	Latitude	Departure	Designation	File
597	1011	70	Longyear	2121.5			648,619.1	882,918.1	Spillway D	Box 34
598	1019	45	Longyear	2045.2			650,037.8	883,475.6	"	"
599	1011	49	Longyear	2037.6			650,503.1	883,658.6	"	"
600	1027	28	Longyear	2220.8			641,237.7	880,083.4	Spillway E	"
601	1018	16	Longyear	2213.0			641,621.1	880,404.4	"	"
602	1012	35	Longyear	2221.2			642,091.0	880,560.3	"	"
603	1012	30	Longyear	2237.7			643,040.2	880,278.7	"	"
604	1018	24	Longyear	2260.0			643,857.1	879,746.0	"	"
605	1019	35	Longyear	2290.8			644,838.8	879,722.1	"	"
606	1017	46	Longyear	2314.1			645,825.9	879,880.2	"	"
607	1016	27	Longyear	2269.3			646,813.0	880,038.4	"	"
608	1012	50	Longyear	2245.9			647,800.1	880,196.6	"	"
609	1012	55	Longyear	2179.1			648,787.3	880,354.7	"	"
610	1027			2106.2			649,774.4	880,512.9	"	"
611	1025	3	Longyear	2100.8			650,761.5	880,671.0	"	"
612	1025	15	Longyear	2151.1			644,211.0	869,486.2	Spillway C	"
613	1023	7	Longyear	2140.3			644,280.9	868,772.5	"	"
614	1022	7	Longyear	2117.8			644,396.3	867,779.4	"	"
615	1022	1	Longyear	2145.6			644,687.1	867,853.1	"	"
616	1023	3	Longyear	2135.3			644,256.7	866,806.2	"	"
617	1020	70	Longyear	2105.0			644,956.2	866,830.7	"	"
618	1021	10	Longyear	2127.5			644,412.1	866,415.8	"	"
619	1018	60	Longyear	2114.2			644,523.6	866,315.4	"	"
620	1018	69	Longyear	2115.1			644,623.5	866,318.9	"	"
621	1018	53	Longyear	2106.9			644,723.4	866,322.4	"	"
622	1021	1	Longyear	2093.0			644,827.6	866,430.3	"	"
623	1018	46	Longyear	2109.4			644,632.2	866,069.0	"	"
624	1016	51	Longyear	2138.3			645,228.4	867,179.6	"	"
625	1020	56	Longyear	2146.4			645,423.6	867,222.8	"	"
626	1020	60	Longyear	2141.9			645,716.5	867,287.7	"	"
627	1016	45	Longyear	2147.8			645,371.4	867,014.2	"	"
628	1020	65	Longyear	2132.6			645,707.4	867,108.6	"	"
629	1024	35	Longyear	2359.4			645,269.1	880,196.2	Spillway E	"
630	1024	22	Longyear	2349.1			645,543.9	879,440.0	"	"
631	1024	16	Longyear	2299.2			645,480.6	879,825.0	"	"
632	1022	20	Longyear	2358.1			645,417.2	880,219.9	"	"
633	*1023	49	Longyear	2317.0			645,873.4	879,584.0	Spillway D	"
634	*1023	45	Longyear	2327.4			645,778.4	880,176.5	"	"
635	*1023	23	Longyear	2182.0			646,173.3	882,112.3	"	"
636	*1023	20	Longyear	2131.6			647,320.3	882,207.2	"	"
637	1021	20	Longyear	2108.8			648,029.8	882,848.5	"	"
638	1021	17	Longyear	2103.2			648,643.0	883,111.7	"	"
639	1038	4	Longyear	2321.3			644,669.7	881,111.1	"	"
640	1038	12	Longyear	2289.8			644,850.1	881,594.6	"	"
641	1031	11	Longyear	2258.5			645,000.0	881,999.7	"	"
642	1031	8	Longyear	2241.1			645,360.1	881,814.7	"	"
643	1030	20	Longyear	2202.9			646,230.0	882,359.8	"	"
644	1031	5	Longyear	2183.4			646,190.0	881,959.8	"	"
645	1030	14	Longyear	2180.6			646,249.9	882,629.9	"	"
646	1031	1	Longyear	2164.8			646,539.8	882,499.9	"	"
647	1035	4	Longyear	2146.2			646,774.9	882,439.9	"	"
648	1032	12	Longyear	2114.9			647,524.9	882,930.1	"	"
649	1032	8	Longyear	2112.7			647,720.0	882,840.0	"	"
650	1032	15	Longyear	2107.4			648,320.9	883,124.9	"	"
651	1030	3	Longyear	2067.9			648,800.1	883,620.3	"	"
652	1032	4	Longyear	2058.3			649,210.1	883,510.6	"	"
653	1030	8	Longyear	2096.5			649,587.0	883,678.2	"	"
654	1028	3	Longyear	2315.3			643,440.0	881,588.3	"	"
655	1022-1034	4	Longyear	2313.9			643,490.1	881,340.3	"	"
656	1035	10	Longyear	2276.8			643,565.1	881,100.4	"	"
657	1029	3	Longyear	2331.2			643,782.8	880,666.4	"	"
658	1033	20	Longyear	2309.9			643,969.9	880,754.4	"	"
659	1030	25	Longyear	2336.8			643,354.9	880,940.4	"	"
660	1035	32	Longyear	2287.9			643,759.9	881,160.4	"	"
661	1031	14	Longyear	2310.9			643,680.0	881,413.4	"	"
662	1039-1033	2	Longyear	2321.4			643,630.0	881,645.3	"	"
663	1032	20	Longyear	2273.2			643,469.7	880,910.4	"	"
664	1033	44	Longyear	2355.8			644,329.9	881,010.6	"	"
665	1038	18	Longyear	2363.3			644,280.2	881,340.1	"	"
666	1033	40	Longyear	2346.5			644,160.3	881,625.0	"	"
667	1036	1	Longyear	2345.1			644,535.5	881,729.9	"	"
668	1034	18	Longyear	2307.1			645,460.1	882,049.8	"	"
669	1036	7	Longyear	2290.8			645,750.1	881,999.9	"	"
670	1035	46	Longyear	2222.2			645,800.1	882,189.8	"	"
671	1038	27	Longyear	2219.0			646,570.2	882,200.1	"	"
672			Govt Labor	2173.8			646,530.0	882,330.0	Test Pit	"
673	1037	1	Longyear	2173.4			647,179.7	882,760.1	Spillway D	"
674	1037	4	Longyear	2158.1			647,850.1	883,050.9	"	"
675	1038	31	Longyear	2102.9			648,351.2	883,289.5	"	"
676	1039	23	Longyear	2138.0			647,097.3	882,275.5	"	"
677	1036	18	Longyear	2298.4			643,435.2	881,849.9	"	"

* Book Lost

TABULATION AND INDEX OF DRILL HOLE LOGS FOR FOUNDATION INVESTIGATIONS FOR FORT PECK DAM - Contd

Hole No.	Field Book Number	Field Book Page No.	Contractor	Ground Elevation	Station	Range	Latitude	Departure	Designation	File
678	1038	36	Longyear	2326.7			643,540.0	881,525.0	Spillway D	Box 34
679	1036	14	Longyear	2298.9			643,595.0	881,260.[illegible]	"	"
680	1037	9	Longyear	2303.8			643,698.0	881,020.0	"	"
681	1038	41	Longyear	2317.5			643,800.0	881,775.0	"	"
682	1035	50	Longyear	2327.2			643,835.0	881,375.0	"	"
683	1040	2	Longyear	2301.5			643,900.3	881,140.0	"	"
684	1037	12	Longyear	2334.3			644,020.6	880,900.0	"	"
685	1036	24	Longyear	2324.1			644,150.9	880,660.0	"	"
686	1035	54	Longyear	2285.6			643,971.2	880,550.0	"	"
700	1148	7	Diamond	2056.0			629,368.5	862,747.1	Borrow D	Box 35
701	1148	15	Diamond	2054.7			629,762.9	863,600.4	"	"
702	1148	23	Diamond	2047.6			630,157.3	864,453.7	"	"
703	1148	28	Diamond	2048.5			630,551.6	865,306.9	"	"
704	1148	32	Diamond	2050.2			630,946.0	866,160.2	"	"
705	1148	1	Diamond	2037.6			631,340.4	867,013.5	"	"
706	1144	23	Diamond	2063.9			631,745.5	867,885.1	"	"
707	1144	18	Diamond	2068.3			632,139.8	868,738.4	"	"
708	1144	30	Diamond	2070.5			632,534.2	869,591.6	"	"
709	1144	35	Diamond	2075.3			632,928.3	870,445.0	"	"
710	1147	8	Diamond	2071.9			632,277.5	870,228.0	"	"
711	1147	13	Diamond	2068.9			631,883.1	869,374.8	"	"
712	1147	20	Diamond	2066.2			631,488.8	868,521.5	"	"
713	1147	3	Diamond	2028.0			631,094.4	867,668.2	"	"
714	1148	37	Diamond	2048.2			630,689.3	866,796.6	"	"
715	1148	46	Diamond	2051.3			630,294.9	865,934.4	"	"
716	1149	15	Diamond	2046.5			629,900.6	865,090.1	"	"
717	1149	9	Diamond	2053.2			629,506.2	864,236.8	"	"
718	1149	2	Diamond	2054.7			629,111.8	863,383.5	"	"
719	1145	11	Diamond	2053.4			628,855.1	864,019.9	"	"
720	1145	38	Diamond	2048.6			62[illegible],2[illegible]9.5	864,873.2	"	"
721	1145	26	Diamond	2047.7			629,643.9	865,726.5	"	"
722	1145	21	Diamond	2049.5			630,038.3	866,579.8	"	"
723	1145	16	Diamond	2044.2			630,432.6	867,433.0	"	"
724	1147	26	Diamond	2066.5			630,837.5	868,304.8	"	"
725	1147	32	Diamond	2070.4			631,231.9	869,158.0	"	"
726	1147	39	Diamond	2069.9			631,626.2	870,011.3	"	"
727	1147	45	Diamond	2072.3			632,020.6	870,864.6	"	"
728	1147	53	Diamond	2071.2			631,369.5	870,647.7	"	"
729	1147	56	Diamond	2072.3			630,975.2	869,794.5	"	"
730	1147	60	Diamond	2069.9			630,580.8	868,941.2	"	"
731	1145	6	Diamond	2038.1			630,186.4	868,087.9	"	"
732	1145	30	Diamond	2047.8			629,781.6	867,216.2	"	"
733	1145	43	Diamond	2050.4			629,387.2	866,362.9	"	"
734	1145	34	Diamond	2047.7			628,992.8	865,509.6	"	"
735	1145	47	Diamond	2045.0			628,598.5	864,656.3	"	"
736	1145	51	Diamond	2035.5			629,230.8	861,257.5	"	"
737	1149	42	Diamond	2040.6			628,974.2	861,893.9	"	"
738	1149	39	Diamond	2040.7			628,717.5	862,530.3	"	"
739	1149	45	Diamond	2055.0			628,323.1	861,677.0	"	"
740	1149	49	Diamond	2051.2			628,066.4	862,313.4	"	"
741	1145	66	Diamond	2039.8			628,460.7	863,166.6	"	"
742	1145	63	Diamond	2041.6			628,204.1	863,803.1	"	"
743	1149	58	Diamond	2050.1			627,809.7	862,949.8	"	"
744	1149	53	Diamond	2054.5			627,415.4	862,096.5	"	"
745	1149	62	Diamond	2054.2			627,158.7	862,732.9	"	"
746	1149	66	Diamond	2047.7			627,553.0	863,586.2	"	"
747	1149	69	Diamond	2043.4			627,922.2	864,385.0	"	"
748	1151	51	Diamond	2049.0			628,341.8	865,292.8	"	"
749	1151	55	Diamond	2047.9			628,736.2	866,146.0	"	"
750	1149	21	Diamond	2048.2			629,130.5	866,999.3	"	"
751	1149	25	Diamond	2044.7			629,524.9	867,852.6	"	"
752	1145	60	Diamond	2070.0			629,929.7	868,724.3	"	"
753	1149	33	Diamond	2073.8			630,324.1	869,577.6	"	"
754	1149	29	Diamond	2079.4			630,718.5	870,430.9	"	"
755	1151	32	Diamond	2053.7			642,988.1	858,829.0	Borrow D	"
756	1151	36		2054.5			643,407.7	859,736.7	"	"
757	1151	40		2047.2			643,827.2	860,644.5	"	"
758	1151	48		2043.6			644,246.7	861,552.2	"	"
759	1151	43		2043.7			644,624.3	862,369.2	"	"
760	1145	56		2039.7			645,128.9	863,458.5	"	"
761	1142	25		2045.1			640,561.3	860,984.3	Winter Harbor	"
762	1142	29		2049.4			640,889.9	861,938.8	"	"
763	1142	33		2044.9			641,035.6	862,397.2	"	"
764	1272									Box 37
765	1275									"
766	1275									"
767	Not Drilled									"
768	1275									"
769	1272									"
770	1275									"

TABULATION AND INDEX OF DRILL HOLE LOGS FOR FOUNDATION INVESTIGATIONS FOR FORT PECK DAM - Contd

Hole No.	Field Book Number	Field Book Page No.	Contractor	Ground Elevation	Station	Range	Latitude	Departure	Desig-nation	File
771	1275									Box 37
772	1274									"
773	1274									"
774	—									
775	1272									"
776	1274									"
777	1275									"
778	1275									"
779	1274									"
780	1272									"
781	1272									"
782	1272									"
783	1272									"
784	1272									"
785	1272									"
786	1272									"
787	1275									"
788	1275									"
789	1275									"
790	1275									"
791	1272-1275									"
792	1275									"
793	1275									"
794	1275									"
795	1275									"
796	1275									"
797	1275									"
798	1275									"
799	1275									"
800	1263	1	Diamond	2062.3			640,936.2	866,309.2	Tunnel	Box 36
801	1263	47	Diamond	2069.2			640,854.4	866,511.5	"	"
802	1258	1	Diamond	2285.0			638,589.4	869,822.0	"	"
803	1263		Diamond	2090.3			640,158.5	867,259.9	"	"
804	1263		Diamond	2090.3			640,174.7	867,385.5	"	"
805	1258	44	Diamond	2245.			638,510.7	869,724.7	"	"
806	1262									
811	1262									"
812	1262									"
814	1261									"
816	1262									"
817	1272									Box 37
818	1272									"
819	1272									"
820	1272									"
821	1266									"
822	1272									"
823	1272									"
824	1272									"
825	1272									"
826	1272									"
827	Not Drilled									
828	1272									"
829	1272									"
830	1272									"
831	1272									"
832	1272									"
833	1269									"
834	1269									"
835	1269									"
836	1269									"
837	1269		G.P. & H.L.	2065.7	85+17.30	0+47.79-U	635,181.5	862,461.0	Left Abut	"
838	1269		"	2054.8	81+77.10	11+83.48-D	636,442.0	862,254.0	"	"
839	1269									"
840	1269		"	2052.7	82+60.52	5+18.21-D	635,803.0	862,457.0	"	"
841	1269		"	2052.4	82+19.90	8+49.69-D	636,121.0	862,355.0	"	"
842	1269		"	2117.7	85+82.62	11+59.15-D	636,250.0	861,896.0	"	"
843	1269		"	2090.0	84+58.02	11+66.63-D	636,309.0	862,006.0	"	"
844	1269		"	2085.9	85+04.24	9+13.72-D	636,060.0	862,070.0	"	"
845	1269		"	2123.3	87+01.62	9+87.18-D	636,044.0	861,960.0	"	"
846	1269		"	2116.6	85+89.77	6+30.49-D	635,767.0	862,111.0	"	"
847	1269		"	2165.	88+84.66	7+88.60-D	635,787.0	861,777.0	"	"
848	1269		"	2115.7	88+49.23	4+43.25-D	635,488.0	861,954.0	"	"
851	1269									"
852	1269									
853	1269									
854	1269									
855	1269									
856	1266									

TABULATION AND INDEX OF DRILL HOLE LOGS FOR FOUNDATION INVESTIGATIONS FOR FORT PECK DAM - Contd

Hole No.	Field Book Number	Field Book Page No.	Contractor	Ground Elevation	Station	Range	Latitude	Departure	Designation	File
857	1266									Box 37
858	1266									"
859	1266									"
860	1266									"
861	1266									Box 37
862	Not Drilled to #900									
908	1272									"
909	1272									"
910	1272									"
912	1275									"
913	1275									"
914	1275									"
915	1275									"
916	1275									"
917	1275									"
918	1275									"
919	1275									"

Transit Books No. 1 through 7 - Books No. 1070 through 1076		Box 34
Level Books No. 1 through 7 - Books No. 1090 through 1099		"
Test Pit "M" "P" "HL" "N" Book No. 1053		"
Freezing Test Book No. 1056		"
Water Measurements in drill holes	Books 1054, 1278	34 & 37
Upper Portal Auger Holes	Books 1213, 1270	36 & 37
Test Pits	Books 1238	Box 36
Auger holes shaft area	Books 1264, 1279	36 & 37
Lower Portal Auger Holes	Books 1265, 1271	Box 37
Test Holes Misc.	Books 1277, 1280, 1281	Box 37
Hole 2WB through 6 WB	Books 1156	Box 35
Hole 7WB through 10WB	Books 1053 and 1156	34 & 35
Hole 24WB through 31WB	Book 1153	Box 35
Test Holes West Abutment	Books 1276, 1277	Box 37
Test Borings - Water Loss	Book 1278	Box 37
Geology Shaft Area	Books 1278, 1282	Box 37
Geology Tunnel	Books 1284, 1285	Box 37
Geology Lower Portals	Book 1286	Box 37
Calyx Holes	Books 1287 to 1301	Box 37
Geology Spillway (Mongold)	Books 1302 to 1317	Box 37

FORT PECK DAM

TABULATION AND INDEX OF DRILL HOLE LOGS FOR

FOUNDATION INVESTIGATIONS FOR FORT PECK DAM (SINCE 1935)

Hole Designation	Date	Station	Range	Type of Drilling	File
PU35/1.6 #1	1940	34+93	1+62-U	Drive	P & O
PU35/1.25	1949	35+00	1+25-U	Drive	"
PD35/3 #1	1940	34+92	3+04-D	Drive	"
PD35/2.75	1950	35+25	2+75-D	Drive	"
PD35/14	1939	35+00	14+00-D	Drive	"
PD35/19.5	1942	35+00	19+50-D	Drive	"
PD40/19.5	1942	40+00	19+50-D	Drive	"
PD45/19.5	1942	45+00	19+50-D	Drive	"
Well #1	1942	47+70	20+00-D	Drive	"
Well #3A	1946	47+70	20+00-D	Jet	"
Well #4A	1946	49+70	20+00-D	Jet	"
PU50/1.25	1950	50+00	1+25-U	Drive	"
PD50/2.75	1950	50+00	2+75-D	Drive	"
PD50/19.5	1942	50+00	19+50-D	Drive	"
Well #2	1942	50+00	20+00-D	Jet	"
PD50/30	1949	50+00	30+00-D	Jet	"
Well #3	1942	50+50	20+00-D	Jet	"
Well #4	1942	51+00	20+00-D	Jet	"
Well #5A	1946	51+70	20+00-D	Jet	"
Well #5	1942	52+00	20+00-D	Jet	"
Well #6	1942	53+00	20+00-D	Jet	"
Well #6A	1946	53+70	20+00-D	Jet	"
PD55/19.5	1942	55+00	19+50-D	Drive	"
Well #7	1942	55+00	20+00-D	Drive	"
Well #7A	1946	55+20	20+00-D	Drive	"
Well #8	1942	56+25	20+00-D	Jet	"
Well #8A	1946	56+70	20+00-D	Jet	"
PD57.5/18.1	1942	57+50	18+10-D	Drive	"
Well #9	1942	57+50	20+00-D	Jet	"
Well #9A	1946	58+20	20+00-D	Jet	"
Well #10	1942	58+75	20+00-D	Jet	"
Well #10A	1946	59+45	20+00-D	Jet	"
PU60/1.6 #3	1939	60+00	1+60-U	Drive	"
PU60/1.25	1951	60+00	1+25-U	Drive	"
PD60/3 #2	1938	59+97	3+11.5-D	Drive	"
PD60/2.75	1950	60+00	2+75-D	Drive	"
PD60/14	1939	60+00	14+00-D	Drive	"
PD60/19.5	1942	60+00	19+50-D	Drive	"
Well #11	1942	60+00	20+00-D	Drive	"
PD60/25	1942	60+00	25+00-D	Drive	"
PD60/30	1942	60+00	30+00-D	Drive	"
PD60/35	1942	60+00	35+00-D	Drive	"
PD60/40	1942	60+00	40+00-D	Drive	"
PD60/45	1942	60+00	45+00-D	Drive	"
PD60/50	1942	60+00	50+00-D	Drive	"
Well #11A	1946	60+70	20+00-D	Jet	"
Well #12	1942	61+25	20+00-D	Jet	"
Well #12A	1946	61+95	20+00-D	Jet	"
Well #13	1942	62+50	20+00-D	Jet	"
Well #13A	1946	63+20	20+00-D	Jet	"
Well #14	1942	63+75	20+00-D	Jet	"
Well #14A	1946	64+45	20+00-D	Jet	"
PD65/19.5		65+00	19+50-D	Drive	"
Well #15	1942	65+00	20+00-D	Jet	"
Well #15A	1946	65+70	20+00-D	Jet	"
Well #16	1942	66+25	20+00-D	Jet	"
Well #16A	1946	66+95	20+00-D	Jet	"
PD67.5/18.1	1942	67+50	18+10-D	Drive	"
Well #17	1942	67+50	20+00-D	Jet	"
Well #17A	1946	[illegible]+20	20+00	Jet	"
Well #18	1942	[illegible]+75	20+00	Jet	"
Well #18A	1946	69+45	20+00	Jet	"
PU70/1.6	1942	70+00	1+60-U	Drive	"
PD70/3	1942	70+00	3+04-D	Drive	"
PD70/14	1942	70+00	14+00-D	Drive	"
PD70/19.5	1942	70+00	19+50-D	Drive	"
Well #19	1942	70+00	20+00-D	Jet	"
PD70/30	1950	70+00	30+00-D	Drive	"
Well #20	1942	71+25	20+00-D	Jet	"
Well #19A	1946	71+45	20+00-D	Jet	"
Well #21	1942	73+75	20+00-D	Jet	"
PD75/19.5	1942	75+00	19+50-D	Drive	"
PU75.94/0.5	1940	75+00	0+50-U	Drive	"
PD75.99/1.76	1940	75+99	1+76-D	Drive	"
PU76.02/2.81	1940	76+02	2+81-U	Drive	Box
PD77.5/19.5	1942	77+50	19+50-D	Drive	"
PU78.94/0.5	1940	78+94	0+50-U	Drive	"

TABULATION AND INDEX OF DRILL HOLE LOGS FOR FOUNDATION INVESTIGATIONS FOR FORT PECK DAM (SINCE 1935) - Contd

Hole Designation	Date	Station	Range	Type of Drilling	File
FD79/3.74	1940	79+00	3+74-D	Drive	P & O
FU 79.01/2.80	1940	79+01	2+80-D	Drive	Box
CD80/0.38	1940	80+00	0+37.5-D	Drive	P & O
FD80/8.3	1940	80+00	8+30-D	Drive	"
FD80/19.5	1942	80+00	19+50-D	Drive	"
FD80.13/22.96	1940	80+13	22+96-D	Drive	"
FU81.77/2.78	1940	81+77	2+78-U	Drive	"
FD82/1.7	1940	82+00	1+70-D	Drive	"
FU84.94/0.5	1940	84+94	0+50-U	Drive	Box 230-232
FU84.98/2.72	1940	84+98	2+72-U	Drive	Box 230
FD85.01/3.75	1940	85+01	3+75-D	Drive	Box 230
FU87.94/0.5	1940	87+94	0+50-U	Drive	Box 232
FU90.93/0.47	1940	90+93	0+47-U	Drive	Box 232
FU93.94/0.5	1940	93+94	0+50-U	Drive	Box 232

SECTION IV - CONSTRUCTION HISTORY

4.1 **GENERAL.** Placement of fill by hydraulic methods started with the 1935 dredging season. At the end of 4 years, a total of 156,000,000 cu. yd. (119,340,000 m^3) of dredged material had been pumped and 122,000,000 cu. yd. (93,333,000 m^3) had been retained in the fill. This method of fill placement was completed on 5 November 1939. A slide occured on 22 September 1938 and displaced 5,000,000 cu yd (3,825,000 m^3) of fill along the upstream face of the dam. Details concerning the slide, the slide investigation, and embankment reconstruction are presented in Section V, Slide Investigation.

4.2 DESIGN OF HYDRAULIC FILL

4.2.1 **General.** A typical cross section of the embankment, which shows the various specified zones, is presented on plate 4-1. The effective size and clay content specified for the hydraulic fill materials are also shown on plate 4-1. The specified mechanical analysis curves for the various materials are presented on plate 4-2. Records of effective size and clay content were taken at each station and were plotted on cross sections. Plates 4-3 and 4-4 present a typical section at station 40+00, which shows the effective size and clay content of the embankment for the entire section as determined by laboratory analysis of permanent record samples taken after the fill was in place.

4.2.2 **Specifications for Hydraulic Fill.** The following is an abbreviated version of the specifications used for placement of the hydraulic fill. The complete specification is presented in Reference 43 listed in the Bibliography of Referenced Data.

4.2.2.1 "The purpose of these specifications is to insure the placement of satisfactory hydraulic fill materials in the Fort Peck Dam. The dam shall be composed of a dense, relatively impervious core, confined by two permeable shells. The core, except the sandplugs, shall be a homogeneous mixture of fine sand, silt and clay. The shells shall be sand and gravel with limiting amounts of clay and silt as hereinafter specified.

4.2.2.2 __General.__ "In order to limit and define the material to be placed, the cross section of the dam is divided into zones as shown on (plate 4-1) which is a part of these specifications.

4.2.2.3 __Zones 1 and 6.__ "The shells below elevation 2,180 ft m.s.l. shall have an average effective size greater than 0.1 millimeter (mm). The shells above elevation 2,180 ft m.s.l. shall have an average effective size greater than 0.05 mm. Below elevation 2,100 ft m.s.l. the average clay content shall be less than 3.0 percent by weight; between elevations 2,100 ft m.s.l. and 2,180 ft m.s.l. the average shall be less than 5.0; and above elevation 2,180 ft m.s.l. the average shall be less than 8 percent.

4.2.2.4 __Zones 2 and 5.__ "Zones 2 and 5, comprising the transition areas wherein the shell material grades to core material, shall be composed of material having an average effective size greater than 0.005 mm. The average clay content shall be less than 10 percent (by weight)."

4.2.2.5 __Zone 3 Below Elevation 2,200 ft m.s.l.__ "Zone 3 material, except the sand plugs, shall be composed of a material having an average effective size less than 0.005 mm. The average clay content shall be greater than 10 percent and less than 30 percent (by weight). The average mechanical analysis of this material shall fall within the limits of curves 1 and 2 (plate 4-2) which is a part of these specifications."

__Zone 3 Above Elevation 2,200 ft m.s.l.:__ "This material shall have an average effective size less than 0.01 mm. The average mechanical analysis of this material shall fall within the limits of curves 1 and 3, plate 4-2."

4.2.2.6 __Zone 4.__ "Zone 4 comprises the area between the minimum and maximum downstream core limits. This zone may be composed of material as defined for zones 3 or 5 by the above specifications."

4.2.2.7 **The Sand Plugs.** "To approximately elevation 2,180 ft m.s.l. the sand plugs that retain the core on each bank at the river section, shall be composed of a material that has an average effective size less than 0.10 mm. The average clay content shall be less than 20 percent (by weight). Above the sand plugs, the core shall be composed of material that has an average effective size less than 0.02 mm. The average mechanical analysis of this material shall fall within the limits of curves 1 and 3, as shown on plate 4-2."

4.3 **FOUNDATION AND ABUTMENT TREATMENT.** As discussed in the section on site geology, the entire foundation of the dam was covered with a clay blanket that was underlain by stable sand. The clay was relatively impervious and had relatively low shear values when saturated. For this reason, the clay blanket was stripped from the foundation of the dam between the abutments to an average elevation of 2,050 ft m.s.l. This operation involved the removal of over 4,000,000 cu. yd. (3,060,000 m^3) of material.

The remaining fine-grained sand is interspersed with layers of coarse sand, gravel, and clay. The numerous interconnecting layers of coarse sand and gravel indicated the advisability of some measures to reduce seepage and prevent possible piping through the foundation. To ensure against this possibility, a steel sheet pile cutoff wall was driven approximately along the axis of the dam into firm shale, forming a continuous diaphragm which extended up both the right and left abutments.

Both the upstream and downstream toes of the dam were constructed of gravel varying in size from ½ to 6 inches (12 to 152 mm). The upstream gravel toe had a maximum width of 225 feet (69 m), a maximum height of 60 feet (18 m), and a crest 30 feet (9 m) wide. The upstream gravel toe was blanketed on the upstream face with field-stone rirap. The downstream gravel toe, 469 feet (141 m) in maximum width, had a crest width of 25 feet (8 m) and a maximum height of 80 feet (24 m).

4.4 **STEEL SHEET PILE CUTOFF WALL.** Reference 32 listed in the Bibliography of Referenced Data discusses the steel sheet pile cutoff wall and should be consulted for detailed information concerning its purpose, installation, and initial operation. The following history of the purpose and installation of the cutoff wall is quoted in part from reference 32.

"The steel sheet pile cutoff wall was installed as recommended by the Board of Consultants at a meeting on 11 January 1934, to provide a relatively impervious curtain of steel extending downward from the impervious core of the hydraulic fill to the impervious Bearpaw shale bedrock to retard the percolation of water through the many relatively discontinuous pervious of semi-pervious strata of the intervening alluvial materials underlying the dam. The wall was installed 37.5 feet (11.4 m) upstream from the axis of the dam, extends 10,146 feet (3,095 m) from station 2+04 in the right abutment to station 103+50 in the left abutment, and contains 1,183,427 square feet (110,060 m^2) of steel sheet piling. Every effort was made during the installation of the piles to drive them to firm shale. The top 20 feet (6.1 m) of the piles were subsequently embedded in the impervious core of the hydraulic fill.

"The specifications called for interlocking piling with a web thickness of not less than 3/8 inch (9.5 mm). The contractor elected to use a shallow arch-type piling with an effective width of 16 inches (406 mm). Piles having a 3/8 inch (9.5 mm) web and weighing 23 pounds per foot (34Kg/m) were used in general for the lower portion of the wall, which averaged about 70 feet (21.3 m) in depth. During the placement operation piles having ½-inch web (12.7 mm) and weighing 28 pounds per foot (41.6Kg/m) were selected and were attached by welding to form the upper portion of the wall. The ½-inch web (12.7 mm) thickness was used in the upper portion of the wall because of the severe driving required to attain the final depths. In the maximum valley section the piling was driven to the then unprecedented depth of 163 feet (49.7 m).

"Driving the steel sheet piling to the required depths demanded much pioneering and experimenting by the contractor as there were no historical records of piling being driven to these depths. The principal items of equipment which were developed on the job were the 196-foot (60 m) high traveling gantry crane and the hydraulic spade jet. The hydraulic spade jet as finally developed contributed much to the success of driving the piling. The main advantage of this type of jet was in deep prejetting with the jet operating in the interlock of the previously set pile. The jets worked best in loams, sand, and sandy-clay, and in this type of material after proper prejetting, a lower tier length of piling would drop almost full length by its own weight. The spade jets were used in prejetting for the entire length of the piling. Round jets with nozzles varying from 1¼ to 1 5/8 (31.8 mm to 41.3 mm) inches in diameter were also used. Normally these round jets were operated on both sides of the pair of piles being driven with usually only one jet in operation at a time. Normally the round jets were used only in driving the upper tiers of piling. All piling were driven to their final positions below the jetting depth with a power hammer operated by either steam or compressed air. Jetting with round jets was never performed at a lower elevation than the bottom of the pile in order to prevent scour of fines and consequent precipitation of gravel and boulders into the path of the pile which would tend to deflect it. When boulders were encountered which blocked the piling, the round jets were employed to cut holes in the form of a semi-circle at the side of the bottom end of the pile to allow the obstacle to slide away from its obstructing position.

"A rapid increase in the speed of penetration of the piling usually indicated that the pile had broken from the interlocks. If a pile began bouncing while being driven it was assumed that a weld had broken, in which case the driving operations were completed unless the break occured above the surface of the ground. The percentage of known broken splices was very small.

"In addition to the main cutoff wall, four steel sheet piling range walls were constructed on the left (west) abutment as successive barriers to any seepage that might occur along the valley line and through the stratified alluvial material found underlying the glacial till overburden on that abutment. These walls, aligned almost parallel to one another, extended from points on the flood plain approximately 200 feet (61 m) from the abutment, up four successive coulees situtated between the axis and the downstream toe of the dam.

"It was originally planned to force grout into the interlocks of the steel sheet piling and along the sides of the piling in the spaces washed out by the water from the jets. The grout was to be forced into position through pipes which in some cases would extend to the bottom of the piling. After initiation of construction, it was decided to abandon grouting entirely as no practical way could be developed to get grout into the interlocks and it was believed unnecessary to grout alongside the piling since these spaces were all filled with material which was washed down from above by jetting on subsequent piling. This material in effect formed a hydraulic fill which it was believed would effectively fill the voids and meet requirements.

"Construction of the cutoff wall was started on 18 August 1934 and completed on 21 December 1935.

During the initial construction, the dam embankment was placed on each side of the river and the core pool water was discharged to the river over cascade-type spillways. Sand was used as a plug at each river end of the core and was also used to serve as a foundation for the wooden spillway structure. At the time of closure, these sand plugs were quite large. Instead of excavating this sand material and replacing with impervious core material, it was decided to install a sheet steel cutoff wall which would extend through the pervious sand and bond the core material already in place to the closure core.

4.5 METHOD OF EMBANKMENT CONSTRUCTION. The construction of the fill was accomplished by the full hydraulic method, using four electrically operated dredge units. One dredge started operation on 13 October 1934 and pumped approximately 800,000 cu. yd. (612,000 m^3) before being forced to discontinue operations for the winter. During the 1935 to 1939 construction seasons, it was possible to operate four dredges an average of 7 months a year, averaging approximately 124,600 cu. yd. (94,860 m^3) of retained material in the fill each day. At the time of the slide (22 September 1938), 104,000,000 cu. yd. (80,000,000 m^3) of material had been retained in the dam.

The embankment was first raised to about elevation 2,168 ft m.s.l. on either side of an 800-foot (245 m) channel section left open for riverflows. During this first phase of construction, the dredge-effluent water from the core pools was discharged back to the river by means of temporary cascade-type spillways on the slopes. When the river was diverted through the tunnels on 24 June 1937 and when the fill extended completely across the valley (closure), the dredge effluent was pumped out of the core pool by four pump barges.

Pumped material was discharged from pocket pipelines along the outside edges of the fill, thus forming beaches sloping toward a central core pool. The resulting gradation of deposited material was from the coarsest on the outer edge of the fill to the finest in the core pool, where the fines slowly settled out, forming a relatively impervious core held in place by the pervious shells.

In order to control the materials in the core, samples were taken at various depths and locations and mechanical-analysis and moisture-content tests were made. Periodic soundings were made to determine the rate at which the core was filling up and the rate of consolidation of the soft material. Subsidence plates and seepage-determination pipes were located in several transverse rows across the dam. The plates were connected to 3-inch (76 mm) pipes which were extended as the fill was built. The pipes were perforated so they could be used for locating the saturation lines through the dam.

4.6 ADDED UPSTREAM BERM BETWEEN STATION 30+00 AND STATION 75+00.

4.6.1 General. In August 1937, the District Engineer proposed that a berm be added upstream from the embankment toe to provide against the possible development of the plastic state in the clay layer that underlies the upstream slope between stations 30+00 and 75+00. Although stability analyses did not necessarily show that failure of the slope was impending, the analyses clearly indicated the relative weakness of this section of the foundation. In view of this fact and considering the unusually rapid placement of fill over the critical section (station 58+00), the value of this precautionary measure was established. A plan view of the added berm is presented on plate 4-5.

4.6.2 Stability Analyses. The following methods were used to evaluate the upstream foundation stability with and without the added berm: (1) Swedish Method - Circle Analysis 1/; (2) Swedish Method - Graphic Analysis 2/; Jurgenson's Method 3/; and Wedge Method (investigation of strength of clay layer to resist a slide along the base of dam from core pressure). Summaries of the stability computations are presented on plates 4-6 through 4-15. The adopted embankment and clay foundation strength constants are presented on plate 4-7 and in table 4-1. Clay foundation strength Cases I, II, and III presented in table 4-1, represent the range of conditions considered in applying laboratory test results to field conditions.

1/ K. Terzaghi, "The Mechanics of Shear Failures on Clay Slopes and the Creep of Retaining Walls." Vol. 10, Public Roads.

2/ W. Fellenius, "Calculations of the Stability of Earth Dams." Second Congress on Large Dams - 1936.

3/ "On the Stability of Foundations and Embankments." Vol. II, Proceedings of International Conference on Soil Mechanics and Foundation Engineering.

TABLE 4-1

STRENGTH CONSTANTS ADOPTED FOR ANALYSIS OF UPSTREAM FOUNDATION

Material	Unit Wt., Tsf	Case I Tan ø	Case I C, Tsf	Case II Tan ø	Case II C, Tsf	Case III Tan ø	Case III C, Tsf
Shell	0.05	0.65	0	0.65	0	0.65	0
Core	0.052	0.20	0	0.20	0	0.20	0
Clay Found.	0.06	0.18	0.15	0.21	0.33	0.24	0.12

Computations were made for sections taken at Stations 25+00, 40+00, 58+00, 65+00 and 75+00. At the critical section taken at station 58+00, computations were made by all four methods. The stability analyses are summarized on plates 4-7 through 4-15.

4.7 CLOSURE. One of the main construction problems was the management of the water flowing in the Missouri River. The mean, maximum, and minimum daily average flows were 10,250 c.f.s. (287 m^3s), 154,000 c.f.s. (4,312 m^3s), and 490 c.f.s. (14 m^3s), respectively. In the initial phase of dam construction, the water was allowed to flow in the river channel, while earthfill was placed on each side of the river to a height of about 130 feet (40 m). The river section in which no fill was placed was approximately 800 feet (245 m) wide. In the final phase, the water was passed through the four 24-foot 8-inch (7.5 m) tunnels while the remaining earthfill was placed.

Closure of the dam, closing off the river channel, and diversion of the riverflow through the tunnels, occurred during the summer of 1937, immediately following the annual spring rise of the river. At that time, it was necessary for the tunnels to be completed and for the dam to be raised on each side of the river channel. The additional height would furnish enough channel portion of the fill to the same height as that on each side of the channel before the next spring flood after closure.

Detailed planning for closure was commenced in 1935 and preparatory work was initiated in 1936 and continued into 1937. Channels 200 feet (61 m) wide were excavated from the river to the inlet and outlet portals, except for "plugs" which were required to prevent the entrance of water into the

tunnels. A levee was constructed on the upstream side of the upstream gravel toe to reduce percolation through the toe. Dredge pipelines were laid to downstream borrow pits and four pump barges were constructed for use in unwatering the core pool after closure. After closure, the determination was made that the most practicable method for disposal of the excess water from the pool would be by pumping. Log booms were constructed upstream from the tunnel intake works. In addition, many advance arrangements were made for construction operations during the closure period; i.e., the Great Northern Railroad Company was requested to make available 500 railroad cars for handling gravel and 120 cars for handling stone.

In the closure section, a railroad trestle was located along the upstream toe and a bridge was along the downstream toe of the dam. Preliminary plans provided for closure at the upstream toe of the dam. A number of considerations influenced the decision to make the closure of the upstream rather than at the downstream toe. One of the reasons for selecting the upstream toe was the fact that the upstream trestle would permit the dumping of rock as well as gravel, whereas the downstream bridge included a 200-foot (61 m) through span which would not permit the dumping of rock in this reach.

The construction forces started the work necessary to implement the plan on 26 June 1937, 11 days before the selected date for closure. The "plugs" in the channels leading to the tunnel portals were reduced to their minimum size of a 50-foot (15 m) top width. Dredges were moved downstream and the pump boats were set in place in the core pool within the closure area. The log booms were placed across the inlet channel. Gravel was dumped at both the upstream and downstream toes in quantities that would not dangerously constrict the channel. As the closure date drew near, the top of the natural inlet plug was reduced in elevation -- first to elevation 2,050, down to 2,047 and then to 2,044 ft m.s.l. In the meantime, the river stage was approximately at elevation 2,037 ft m.s.l.

Until 23 June 1937, all phases of the closure operation had proceeded smoothly and in accordance with plans. On that date, however, an incident happened at 3 p.m. which required that the plans be altered radically. At that time, movement of a portion of the sand shell occurred on the river sideslope of the right- or east-bank section of the earthfill just upstream from the main east pier of the through channel span of the downstream railway bridge. This shifting of the sand shell placed a tremendous load against the east pier supporting the 200-foot (61 m) through span of the bridge and resulted in an 8-inch (203 mm) horizontal movement and the opening of a 6-inch (152 mm) crack in the concrete pier. Observations indicated that the crack was slowly widening. Without delay, 30 carloads of gravel totaling 1,200 cu. yd. (918 m^3) were dumped on the riverside of the pier, which arrested the movement. Scour by the river at the toe of the fill and rapid drawdown following the spring flood were believed to have been the direct cause of the slide which damaged the bridge pier.

The river continued to fall rapidly and further earth movements were considered probable. It was realized that if this occurred the damaged pier might fail, thus creating a serious situation since the bridge was the only artery for rail and vehicular traffic across the river. Furthermore, closure probably would be delayed a full year. As a result of this condition, it was decided on the evening of 23 June 1937 to make closure on the next afternoon and to effect the closure at the downstream toe. As a sufficient number of cars filled with gravel and stone were on the east side of the river near the bridge, it was decided that closure could be effected more quickly than at the upstream toe and that closure operations would ensure protection of the main bridge span and would provide a higher water level which would further reduce the probability of movement of the fill.

At 1 a.m. on 24 June 1937, the tunnels were cleared and ready for diversion of the river. At 4:20 a.m., the plug at the inlet to the tunnels was broken and at 7 a.m., the plug at the outlet channel was also broken.

Since the single through span of the Missouri River bridge at the downstream toe was not designed to permit the dumping of rock from its sides, boulders had to be dumped at the ends of the span before closure was commenced. To assist in making the closure and particularly to handle the rock, a derrick boat equipped with a 3 yard (2.7 m) orange-peel bucket had been placed on the right bank just below the through span of the bridge. During the day of the 24th of June, and until closure started in the afternoon, the derrick boat laid a rock sill as far as it could reach into the channel to assist in retaining the gravel which would be placed in the river. After closure started, a fleet of 13 large bulldozers was assembled, 9 on the left side of the channel and 4 on the right side. Preliminary to starting closure, 45 cars of rock and 16 cars of gravel were dumped at the ends of the span. When closure began, 480 carloads of gravel were on hand to complete the closure.

When closure commenced at 4:51 p.m. on 24 June, flow through the tunnels had attained a rate of 2,400 c.f.s. (67 m^3s), while the total flow of the Missouri River was approximately 10,000 c.f.s. (765 m^3s). Trains of gravel, consisting of 40 cars each, were dumped in rapid succession through the channel span of the downstream bridge after the closure operations were started. At 7:05 p.m., the downstream gravel toe had been raised above the water surface in the river and the entire flow, less seepage and storage, was passing through the four diversion tunnels. In 2 hours 14 minutes, 140 carloads of gravel had been dumped, completely closing the Missouri River. Prior to closure, the elevation of the water surface was 2,037 ft m.s.l. After the channel was closed and the entire flow diverted through the tunnels, the pool rose rapidly to elevation 2,046 ft m.s.l. Pumping of fill into the closure section commenced at 9:20 p.m. the same evening and dumping of gravel and rock continued throughout the night to strengthen the closure. Closure of the upstream toe was accomplished at 1:00 a.m. on 26 June 1937.

The dumping of gravel continued at the rate of approximately 200 cars per day until both the upstream and downstream toes were completed to full height in the closure section. The dredges continued pumping into the

closure throughout the season, and by 5 November 1937, the core pool for the entire fill across the river valley was brought to a continuous elevation of 2,176 ft m.s.l. With the fill at this elevation, the maximum flood of record and also the spillway design flood could be passed through the tunnels without overtopping the embankment.

As originally planned, the upstream toe would have been completed before closure except for a 211-foot (64 m) gap in the river channel. This gap would have been closed by dumping gravel and rock in shallow lifts entirely across the 211 foot (64 m) width, thereby avoiding a concentration of the flow in a smaller width. When the decision was made to close the dam at the downstream toe, it was necessary, however, to alter this plan since rock could not be dumped from the downstream bridge. As a result, while gravel was dumped over the full width of the opening, a pinching operation was effected by the use of bulldozers operating on both sides of the stream. This plan was successful because of the enormous quantity of gravel which could be dumped in a very short time.

4.8 EMBANKMENT COMPLETION.

4.8.1 Elevation 2,250 ft m.s.l. to Elevation 2,275.5 ft m.s.l. The Board of Consulting Engineers recommended that the embankment fill material above elevation 2,250 ft m.s.l. be placed by rolled fill methods. Also, that the placing of this fill be deferred until completion of the upstream berm. The contract for embankment construction above elevation 2,250 ft m.s.l. was advertised during January of 1940 and was awarded to J. A. Tertling and Sons of Boise, Idaho, with the notice to proceed being issued on 22 March 1940. Actual work was started on 18 April and was completed on 15 October 1940.

The earthwork quantities required to complete the work amounted to 1,400,000 cu. yd. (1,075,000 m^3) of pervious fill and 70,000 cu. yd. (53,500 m^3) of impervious fill (glacial fill). The Contractor moved the pervious material using large Letourneau scrapers and Caterpillar diesel

tractors. The scrapers dumped the material on the fill in about 4-inch (100 mm) lifts. Traffic compaction from the scrapers and tractors was sufficient to yield a fill density of about 100 p.c.f. (1,620 kgm^3). The impervious glacial fill care material was hauled by truck from the left abutment borrow area and stockpiled on top of the dam. If was then reloaded into scrapers and spread in lifts not exceeding 8 inches (200 mm). After being spread, the impervious fill material was ripped with a scarifier, watered, and then rolled using two pair of tandem sheepsfoot rollers. Usually six to eight passes by the roller would yield the desired density of 105 p.c.f. (1,700 kmm^3). A moisture content of from 14 to 16 percent (dry weight) was required to ensure proper compaction of the impervious fill material. At the completion of this contract, the embankment had a crest elevation of 2,275.5 ft m.s.l. and a crest width of 100 ft (30 m).

4.8.2 <u>Final Topping Out in 1946 and 1948.</u> By 1944, the subsidence of the dam, due to consolidation and settlement of the earthfill and the underlying foundation materials, had stabilized sufficiently to permit bringing the embankment to its ultimate gross design grade. In order to obtain an embankment crest road that could be maintained at a minimum of expense for snow and sand removal and to provide an unobstructed view of the lake, the finished net elevation of the dam crest was established at elevation 2,280.5 ft m.s.l. and in conformance with the original plan for the design of the crest a minimum crest width of 50 ft (15 m) was maintained. The regular observations of settlement pipes across the top of the dam furnished the needed data to compute the gross grade necessary in order that the net grade across the top of the dam would be 2,280.5 ft m.s.l. in the year 2000. It was considered that by the year 2000 the indicated rate of settlement would be so slow that it would no longer be of major concern in maintaining design grade.

The material for raising the crest from elevation 2,275.5 to 2,280.5 ft m.s.l. was available from excess fill material on the downstream slope of the dam above elevation 2,227 ft m.s.l. and from borrow pits on the left abutment. The slope of the downstream face of the main section was established as 1 on 4 and on the dike section the 1 on 3 slope was maintained.

On 30 April 1946, a contract was awarded to Northwestern Engineering Company of Rapid City, South Dakota, for raising the dam to the extent necessary to insure a net elevation of 2,280.5 ft m.s.l.; construction of a road across the top of the dam, except for leveling and wearing courses; installation of a night lighting system; and for other items which were not related to the dam proper. Notice to proceed was given on 24 May 1946, and the work was completed on 20 June 1947.

The fill material from the downstream face of the dam was moved by carryalls, terra-cobras, and clamshells, and from the glacial till borrow pit on the left abutment by truck. The pervious material was placed first, and the finishing course consisted of glacial till. A layer of glacial till 6 inches (150 mm) deep was placed on the downstream slope for the first 10 ft (3 m) down in order to lessen erosion by wind and water action. The material for the main fill was placed in 8-inch (200 mm)) lifts, moistened, and then mixed by motor patrols and rolled by sheepsfoot roller. After the embankment was completed, the downstream face of the dam to elevation 2,227 ft m.s.l. berm was gone over with a lister and then seeded with a mixture of crested wheat grass, sweet clover, and oats. A part of the base course was also included under the contract and consisted of a course of gravel 41 ft (12 m) wide and 12 inches (300 mm) thick at the crown. A gravel walk was placed between the roadway and the rock crest a distance of 5 ft (1.5 m). On the upstream face the 18-inch (460 mm) thick gravel blanket was extended to the crest and the rock riprap was relayed along the crest to elevation 2,280 ft m.s.l.

In 1948, a contract was awarded to S. J. Groves & Sons of Minneapolis, for considerable construction work on the project, and this included the bituminous pavement on the crest of the dam road. The notice to proceed was given on 10 September 1948, and the contract was completed on 25 September 1950.

SECTION V - SLIDE INVESTIGATION

5.1 **GENERAL.** Actual construction of the dam was nearly completed when a slide involving 5,000,000 cu. yd. (3,825,000 m^3) occurred on 22 September 1938. The fill had been raised to an average elevation of 2,255 ft m.s.l. or within 20.5 feet (6.2 m) of the proposed top. The slide occurred on the upstream slope between station 2+50 and station 31+00. After the slide, the minimum elevation of the downstream shell was 2,236 ft m.s.l., well over any lake elevation that might result from floods.

To facilitate the recovery of equipment, field stone, and quarry stone, the construction of the new roads on the slide area was started 23 September 1938. Salvage operations involved the use of cranes, power shovels, and trucks. On 24 September, construction of a railroad switchback up the downstream face of the dam was started so that the placing of quarry stone on the unaffected portion of the upstream face and the operation of the quarry could continue. On 27 September, this new railroad was completed.

By 30 September 1938, three dredges were back in operation: one dredge pumped material on the downstream berm of the dam, another pumped into the 2-mile long dike on the west end of the dam, and the third extended the upstream berm from station 70+00 toward the left abutment.

A pump barge had to be placed in the damaged area to handle wastewater during the dredging operations in 1939. The pump barge was taken from the west end of the main core pool. The barge was skidded into the reservoir and placed into position in the damaged area, which was above the reservoir level, by means of locking methods. The operation was completed on 10 October 1938.

On 13 October 1938, the fourth dredge started pumping the protective ring dike on the upstream side of the slide. On 15 October 1938, a second dredge started pumping into this ring dike. Quarry rock and boulder salvage operations proceeded, clearing first those areas required for fill

operations. Salvage operations were completed 8 November 1938, and pumping of the ring dike was completed to elevation 2,160 ft m.s.l. on 24 December 1938.

5.2 **BOARD OF CONSULTANTS.** Prior to the start of construction on the Fort Peck Dam, a board of consulting engineers consisting of Messrs. William Gerig, O. C. Henry, Louis C. Hill, Warren J. Mead and Thaddeus Merriman, was employed to advise on design and construction methods. The membership of the board was reduced by the deaths of Mr. O. C. Henry prior to the slide and of Mr. L. C. Hill soon after the slide. Immediately after the occurrence of the slide, Dr. Arthur Casagrande, Dr. Glennan Gilboy, and Messrs. I. B. Crosby, J. D. Justin, W. H. McAlpine, and C. W. Sturtevant were added to the original board. The board was requested to visit Fork Peck, as necessary, to inspect the work and consult the records. The board was requested to submit a memorandum upon completion of its first visit that set forth the following:

Any subsurface investigations or tests that were deemed advisable, other than those already scheduled; and

The boards opinion on the emergency program then underway to take care of the riverflow during the spring runoff in 1939.

The information obtained from the slide investigation was to be submitted to the members of the board as it became available, so that a full meeting could be held as soon as practicable to consider the following points:

Final design for reconstruction of the slide area;

Recommendations as to whether changes or additions were necessary or advisable in any other portions of the dam;

Recommendations as to whether additional precautions were necesary or advisable in bringing the dam to final grade; and

Determination of the cause of the slide.

5.3 **DATA MADE AVAILABLE AS RESULT OF INVESTIGATIONS.** As a result of the investigations by the District Engineer, the following items were included among the data made available to the board.

Records of laboratory testing covering:

Mechanical analysis of materials.

Void determinations.

Relative density determinations.

Water content of samples.

Consolidated shear tests.

Quick shear tests.

Triaxial compression tests.

Critical density determinations.

Permeability tests.

Mineralogical examinations.

Photoelastic models for stress analysis.

Field compaction tests.

Field shear tests on bentonite insitu.

Horizontal and vertical movements of reference points.

Location and rate of fall of saturation line.

Hydrostatic pressures in foundation.

Peg model of slide and foundation.

Glass model of slide and foundation.

Descriptions of slide and its progress as obtained from eyewitnesses.

Core drill records from more than 200 drill holes measuring 2 inches (50 mm) to 6 inches (150 mm) in diameter that were drilled after the slide in the dam and foundation. Photographs and core records were taken of seven Calyx core drill holes 12 inches (300 mm) to 36 inches (900 mm) in diameter. The slide material was frozen and then drilled to secure 955 feet (290 m) of cores showing exact condition of materials in slide and foundation.

Records and photographs of two exploratory tunnels, one measuring 158 feet (48 m) long and the other 151 feet (46 m) long, showing condition of weathered shale, subfirm shale, and penetration of water and faults.

Data and tests from five shafts totaling 312 (95 m) in the dam outside of slide areas.

Geological cross sections No. 1 to No. 26 showing conditions after slide.

Maps showing distribution of materials in slide area.

Detailed plans and progress cross sections of the dam.

All data on foundation explorations made prior to the slide.

Rate and time of placing fill.

Core-pool limits during construction.

Mechanical analysis of fill material.

Subsidence records.

Core-consolidation records.

Photographs and records of construction operations.

Aerial photographs.

Cross sections and topographical maps showing comparison of dam and foundation before and after slide.

Maps and photographs of trestle and piling before and after slide.

Stability analyses made on sections of the dam as constructed and on numerous sections proposed for the reconstruction of slide area and strengthening of other portions of the dam.

5.3.1 Earth Shock. A check was made to determine if any disturbances, such as an earthquake, were recorded at or before the time of the slide. A report from the records of the nearest seismograph, which was located at Bozeman, Montana, indicated that between the dates of 11 September and 23 September 1938, there were no disturbances of sufficient intensity to have had any effect on the Fort Peck Dam.

5.3.2 **Explorations.** Exploration of the slide area was started 25 September 1938. A series of boring locations was established throughout the slide area in such a manner that geologic cross sections could be made.

The holes were drilled with core-drill and churn-drill rigs. Samples of material above the shale contact were taken on 2½-foot (0.76 m) intervals and continuous cores of shale were taken.

Seven large diameter borings were made in the slide area and two borings were made into undisturbed portions of the foundation by means of Calyx drill rigs. In order to obtain undisturbed cores, portable refrigeration plants were used to freeze the material above the shale.

Test pits were dug in several locations on the unaffected portion of the dam and in the flood plain below the dam to obtain undisturbed samples of shell and foundation material. Two drifts were dug into the right abutment. The purpose of these excavations was to observe the geological conditions in the abutments, to obtain samples of material encountered, and to perform tests on the material in place.

A summary of the explorations shows that a total of 145 separate holes were drilled with core-drill and churn-drill rigs through 12,096 feet (3,689 m) of fill material and 5,313 feet (1,620 m) of foundation shale. The large Calyx holes were drilled a total distance of 1,172 feet (357 m). The total footage of shafts sunk was 335 feet (102 m). The two drifts were driven a total distance of 328 feet (100 m).

5.3.3 **Geological Features.** Twenty-six geologic cross sections of slide area were drafted; one series ran parallel to the axis, one at right angles, and one diagonal from northeast to southeast. The locations of all exploratory holes, shafts, and drifts are shown on plate 5-1. A plan view showing the surface geology of the slide area is presented on plate 5-2. Geologic cross sections 1 through 8 are presented in appendix B of reference 31. In general, these cross sections show:

The overburden materials and of the structure of the faults under the right abutment.

The elevation at which the maximum movement took place.

The distribution of the slide material.

Position of the most important bentonite beds.

The location of fault "A" in the shale.

Thickness of weathered and subfirm shale.

5.3.4 **Tests.** Mechanical analyses were made for the purpose of classifying the materials. Undisturbed samples were secured from various parts of the slide area, from the test pits and drifts, and from 8-inch- (200 mm) diameter holes, on which complete laboratory tests were performed. A summary of the laboratory test procedures is presented on plate 5-3. The test results are presented on plates 5-4 through 5-13 and on plates 5-18 through 5-30. The test results are summarized on plate 5-31. In general, laboratory tests indicated that both the fill and the majority of the foundation materials had a satisfactory degree of stability. Considerable variation was found in the bentonite seams, however, and tests indicated that the shearing strength of the softer grades of bentonite was extremely low.

Tests were made on portions of the hydraulic fill placed after the slide to determine the feasibility of further compacting the hydraulic fill by using heavy tractors. It was found that in order to secure uniform additional compaction, methods for handling the fill materials would be necessary which would interfere considerably with placement of the fill. It was therefore decided not to use tractors to compact the hydraulic fill material. Results of the field compaction tests are presented on plates 5-14 through 5-17.

5.3.5 **Stability Analyses.** Both static-slide and elastic-theory analyses were made on various sections of the dam. The latter method of analysis, as developed by the Fort Peck District, is fully described in reference 19. Plates 5-32 through 5-35 present critical sections of the slide area just prior to the slide. These sections were analyzed to determine values of friction and cohesion required in the foundation for a factor of safety of 1.0. These computed values, together with the conservative values for the shearing strength for the core and shell material, based on the summary of laboratory tests presented on plate 5-31, were used in the reconstruction analyses presented on plates 5-36 through 5-41. Laboratory shear-test results were used throughout the analyses of the sections at stations 58+00 and 85+00 presented on plates 5-42 and 5-43. The stability analyses of the proposed plan show a minimum safety factor of 1.5.

5.3.6 **Summary.** The following items summarize pertinent information obtained as a result of the slide investigation:

The upstream shell moved in mass, carrying the rockfacing practically intact upon it.

A substantial portion of the trestles and pile bents buried in and under the upstream toe moved out intact.

The west part of the slide was limited to about station 27+00, 300 feet (91.5 m) short of the berm which had been previously placed from station 30+00 to the west. Section IV, Construction History - Paragraph 4-6, "Added Upstream Berm Between Stations 30+00 and 75+00."

The core material showed remarkable stability after being subjected to the rapid outwash of core water.

The core pool at no time overtopped the shell.

The explorations made subsequent to the slide indicated distinct shear planes on or in the weathered portions of the shale foundation and in the bentonite seams which lay, in general, horizontal within the shale and which had a maximum thickness of about 15 inches (380 mm).

Bentonite seams uncovered in exploratory tunnels and exploratory holes were saturated and, in some cases, under pressure.

Most of the fill materials involved in the slide showed little change in stratification.

Shale on the right abutment moved down the "A" fault plane.

No shale movement was indicated east of fault "A."

The upstream shell of the dam remained intact on the right abutment east of about station 10+00.

5.4 CONCLUSIONS AND RECOMMENDATIONS OF BOARD.

5.4.1 **Cause of the Slide.** The slide in the upstream portion of the dam near the right abutment was due to the fact that the shearing resistance of the weathered shale and bentonite seams in the foundation was insufficient to withstand the shearing force to which the foundation was subjected. The extent to which the slide progressed upstream may have been due, in some degree, to a partial liquefaction of the material in the slide.

5.4.2 **Reconstruction in Slide Area.** The slide area should be reconstructed as shown in plan on plates 5-44 and 5-45 and in cross sections shown on plate 5-46.

The board agreed that the shell of the reconstructed section could be built by either hydraulic fill or rolled-fill methods and recommended that the core be constructed of rolled impervious glacial fill from the left abutment to a minimum width of 15 feet (4.6 m) at elevation 2,255 ft m.s.l. and 50 feet (15.2 m) at elevation 2,120 ft m.s.l.

The board recommended that the plan for reinforcing the old core by means of a single row of steel sheet piling, as proposed by the District Engineer, be adopted. A steel sheet pile wall was, therefore, constructed to connect the undisturbed portion of the hydraulically-placed core and the impervious abutment material with the mechanically-placed glacial till core, which was constructed during the rebuilding of this portion of the dam. The purpose of this piling was to provide a positive cutoff wall where it was not practical to excavate all the disturbed material down to sound core or foundation material. This wall extended from station 4+80 at the east abutment to station 25+70 along the axis of the dam and was in effect part of the core of the dam."

The board approved the exploratory program outlined by the District Engineer covering installation of piezometer pipes in the shale of both abutments for the purpose of monitoring hydrostatic pressures. The board further approved the plan of the District Engineer to install drainage wells at such points as the piezometer measurements indicated drainage would be desirable.

The board considered in detail the question of stripping disintegrated shale from the east abutment and examined the results of shear tests and stability analyses made by the District Engineer. As a result of this examination, the board concluded that the flat slopes of the reconstructed section would result in shear stresses in the disintegrated shale of very low intensities. An adequate factor of safety was presented so removal of the disintegrated shale was not necessary.

The board considered the question of grouting the fault zones in the shale in the east abutment and approved the plan of the District Engineer for further study of this problem.

5.4.3 **Treatment of Portion of Dam Unaffected by Slide.** The board recommended that the portion of the dam unaffected by the slide be strengthened by the addition of upstream fill as shown on plates 5-46, 5-47 and 5-48.

The board recommended that the material in the added upstream fill be the same as or coarser than the original shell material. The board believed that this material would be sufficiently free-draining so no special provision for drainage would be necessary.

5.4.4 **Compaction of Hydraulic Fill.** In the construction of the berms on the upstream slope of the dam by hydraulic means, the board recommended that tractors be used on the beach to secure as great a degree of compaction as may be practicable without interference with the hydraulic placement of

the material. The board recommended that the use of these tractors be continued to such an extent as necessary to demonstrate whether or not worthwhile additional compaction is obtained.

5.4.5 **Construction Above Elevation 2,250 ft m.s.l.** The board recommended that embankment fill above elevation 2,250 ft m.s.l. be placed by rolled-fill methods and that the placement of this fill be deferred until the recommended berms were completed.

5.4.6 **Dike Section.** The opinion of the board was that the dike section forming the wing of the dam on the left abutment was satisfactory as completed.

5.4.7 **Treatment of Intake Structure.** The opinion of the board was that the grading proposed by the District Engineer for the hillside at the intake reduces to a minimum the probability of serious slides in the hillside which might interfere with the intake.

The opinion of the board was that the proposed plan of filling required the strenthening of the headwall on the reservoir side of the intake and that, in connection with this strenthening, attention should be given to providing easier passage for the water through the intake and into the tunnels. The board recommnded that end ramps to facilitate the cleaning of trash rocks should be constructed of reinforced concrete with a smooth surface.

5.4.8 **Deflection Records.** The Board examined the records of vertical and horizontal deflections of reference points in the unaffected portion of the dam and foundation. The board was of the opinion that these movements conformed to expected normal readjustments of the materials in the dam and foundation and recommended that these observations be continued.

5.4.9 **Compilation of Notes.** The board recommended that the District Engineer assemble and correlate in permanent form all data pertaining to the mode of occurrence of the slide, the investigations and analyses made in connection with the slide, and the plans for reconstruction in order that complete and accurate information may be made available to the engineering profession.

SECTION VI - EVALUATION OF RIPRAP SLOPE PROTECTION

6.1 DESCRIPTION OF RIPRAP SLOPE PROTECTION (ORIGINAL CONSTRUCTION).

6.1.1 **General.** A plan view of the project and a typical embankment section are presented on plate 6-1. Also presented on this plate is a wind rose and other pertinent data used in the evaluation. This evaluation covers the riprap slope protection above the elevation 2,212 ft m.s.l. berm. This reach is subject to more wave action during normal operations and has received preventive maintenance repairs.

6.1.2 **Upstream Shell Material.** The shell material consists of medium to fine sand with a median size of about 0.25 mm and a D_{85} size that varies from 0.30 to 0.6 mm. Plate 6-2 shows the approximate gradation of this material that provides a base for the gravel bedding.

6.1.3 **Gravel Bedding.** The gravel bedding material generally consists of clean gravel well graded between 4 inches (100 mm) and ½ inch (13 mm). Plate 6-2 shows the gradation of the gravel bedding material.

6.1.4 **Riprap.** The upstream face of the dam is generally protected by large quarry stone from Snake Butte, which is located about 100 miles west of the site. This rock is greenish-gray in color and has a unit weight of about 175 lb.cu.ft. (2,830 kg m^3). The weight of the riprap stone varies from 2,000 pounds (900 kg) to about 40,000 pounds (18,000 kg); the median size by weight is 15,000 pounds (6,800 kg). Cranes were used to unload, individually place, and position each stone on the gravel bedding layer. The riprap gradation is shown on plates 6-2 and 6-3.

6.2 PERFORMANCE HISTORY.

Initial erosion of bedding gravel was noted in an inspection made during October and November 1948. Pictures were taken of gravel erosion but no subsidence was noted in this inspection. During an inspection made in December 1952, increased gravel erosion was noted and two areas were found where considerable subsidence had occurred. These areas

were repaired by Government forces by adding gravel and filing the void spaces between the large rock with spalls up to 12 inches (300 mm) in size. Experimental blasting was performed in one area to reduce the size of large rock and furnish the spalls for filling voids. During an inspection made in December 1954, 45 areas were found where subsidence could be noted or where subsidence was imminent due to sand being pulled through the gravel bedding.

6.3 UPSTREAM FACE REPAIR CONTRACTS.

6.3.1 First Experimental Contract. This contract was completed during 1953 after the reservoir was lowered below the work area. This contract covered an area 60 feet (18 m) wide between station 66+40 and station 81+00. The work consisted of reducing the size of existing facing rock, generally those larger than 6,000 pounds (2,700 kg), by drilling, blasting, and rearranging the resultant smaller rock to produce a reasonably well graded protective layer over the gravel bedding layer.

6.3.2 Second Experimental Contract. The second experimental contract was completed during 1958 and consisted of furnishing and placing rock spalls on the upstream face of the dam in such a manner as to fill the voids between the existing derrick stone riprap to prevent further erosion of the underlying gravel blanket. The rock spalls were reasonably well graded and met the following gradation requirement:

Sieve Square Mesh (inch/mm)	Percent by Weight Passing
12/300	100-90
6/150	60-30
3/75	10-0

Hand placement was required as necessary to place suitably-sized rock in unfilled voids between the existing quarry stone after the initial placement of the rock.

6.3.3 **Upstream Face Repairs - Third Contract.** The third contract for the repair of the upstream face used the method developed by the second experimental contract and allowed the contractor to use a stockpile of large derrick stone at Fort Peck as a source of supply. The gradation of the roc spalls was the same as for the second experimental contract and the amount of rock to be placed was determined as 400 pounds per square yard (2.5 kg per m2).

6.3.4 **Summary.** The repair work on the upstream face of the Fort Peck Dam was performed as preventive maintenance and was completed before any appreciable damage had occurred. The material as originally placed did not meet basic filter requirements but performed so long as a bedding layer in excess of 12 inches (300 mm) was maintained. The repair contracts developed a rock spall cover to prevent further erosion of the gravel bedding layer. It is anticipated that trouble areas which develop in the future can be treated by Government maintenance forces with materials at hand.

6.4 EVALUATION OF SLOPE PROTECTION.

6.4.1 **Adequacy of Filter Design.** As shown on plate 6-2, the gradation of the gravel bedding layer is completely inadequate to meet present-day filter criteria between the fine embankment shell material and the very large riprap stone. In practice, it was found that the 18-inch (460 mm) layer of gravel was thick enough to sufficiently dampen the flow due to wave surges so the shell material was not drawn through the coarse bedding layer. When the gravel layer was eroded to a thickness of about 12 inches (300 mm) or less in the large voids between the individual pieces of riprap, the sand shell material would start to be pulled through the bedding layer and a subsidence could be noted. The gravel bedding layer was eroded from between and under the large riprap in numerous areas and troublesome areas could be noted by the size of the gravel windrow at the low waterline in the fall of each year.

6.4.2 Adequacy of Riprap Stone. The following table 6-1 compares as-built gradations with gradations required based on current criteria.

TABLE 6-1

RIPRAP STONE
AS-BUILT VERSUS REQUIRED GRADATIONS

	As-Built*	Method A Scripps Wave Ht and EM 1110-2-2300 Nomograph	Method B SMC Wave Ht & WES Riprap Formula 1/
Wave miles/km			
Fetch - miles and direction	-	20/32 SSW	11/18 SSW
Wind - mph/kmh	-	60/97	60/97
Wind duration - hours	-	2.8	1.5
Wave height - feet/m	-	13.0/4	8.3/2.5

*As Designed Wave Data Not Known

	As-Built*	Method A	Method B
Filter			
Thickness inches/mm and material	18/460; gravel		
Median size - inches/mm	1.5/38		
Spalls			
Thickness and material	As required-crushed derrick stone		
Median size - inches/mm	6/152		
Riprap			
Embankment slope	1 on 3.5	1 on 3.5	1 on 3.5
Layer thickness - inches/mm	53	30	-
Unit weight -pcf/kgm^3	175/2830	175/2830	175/2830
K_{RR} in WES formula	-	-	1.7
Rock Size			
Maximum - p/kg and	40,000/18,000	3,200/1,450	10,400/4,700
inches/mm	73/1,850	34/860	48/1,220
Minimum - p/kg and	2,000/900	100/45	644/290
inches/mm	27/690	11/280	20/500
Average - p/kg and	15,000/6,800	800/360	2,900/1,300
inches/mm	53/1,350	22/560	33/840

The above tabulated data for riprap stone are plotted on plate 6-3.

1/ WES Miscellaneous Paper 2-465 "Design of Riprap Cover Layers for Railroad Fills, Ice Harbor, and John Day Lock and Dam Projects," January 1962.

6.5 CONCLUSIONS. The difficulties of riprap subsidence and erosion of the underlying materials experienced at this site emphasize the importance of proper filter design. The average size of the riprap stone is more than five times heavier than that required by the very conservative WES riprap formula. The gravel bedding placed during original construction, however, is too coarse to prevent migration of the fine shell material and too fine to resist erosion from between and under the riprap stone. It is anticipated that riprap subsidence will be a continuing problem because the repair spalls, which are too small to resist design wave heights, will be displaced during storm periods.

SECTION VII - EMBANKMENT, FOUNDATION, AND ABUTMENT SEEPAGE OBSERVATIONS

7.1 **GENERAL.** The seepage performance at Fort Peck is covered in detail in references 32, 33, 40, 41, 42, and 43. Plate 7-1 is a plan view drawing which shows the locations of wells and piezometers for the main dam and left abutment.

7.2 **FOUNDATION DATA.** Plates 7-2 through 7-5 present soil profiles beneath the main embankment and along the downstream toe of the dam. The profile shown on plate 7-2 is located along the cutoff wall which is 37.5 feet (11.4 m) upstream from the axis. This plate shows generalized foundation conditions and the penetration of the sheet piling at the cutoff wall. The profiles shown on plates 7-3 and 7-4 are at stations where piezometers are installed. These profiles will be referred to in the following discussions of piezometric observations relating to head loss and seepage gradients. The profile shown on plate 7-5 is along the downstream toe of the dam. Plate 7-6 presents a plan view of the embankment superimposed on a contour map of the top of shale bedrock. Also shown are the locations of all drill holes used to determine the bedrock contours.

7.3 **DOWNSTREAM PRESSURE RELIEF WELLS.**

7.3.1 **Previous Reports and Correspondence.** References 29 and 33, listed in the Bibliography of Referenced Data, discuss the temporary and permanent pressure relief well system and should be consulted for detailed information concerning the history, design, and operation of the temporary and permanent pressure relief well system.

7.3.2 **History Prior to Installation of Relief Wells.** A system of pressure relief wells was not included in the original design of the Fort Peck Dam. The problem of underseepage was recognized and a sheet steel pile cutoff wall was installed to cut off or limit the underseepage. During the initial years of operation, the reservoir was at a low stage and hydrostatic pressure in the pervious strata of the foundation was not excessive. During

1937, several test holes had been drilled in the valley downstream from the dam. One of these, at the downstream toe of the dam and penetrating to the pervious gravel strata of the foundation, showed an artesian flow and was left in place. Pressure and discharge measurements were made on this well from time to time. During the spring of 1942, the reservoir filled at a rapid rate, and it was noted that the pressure of the artesian well had increased considerably. When the reservoir reached elevation 2,174 ft m.s.l., which was 76 feet (23 m) below full pool elevation, the pressure had become so great that the water broke up through the soil around the outside of the pipe. This uncontrolled seepage soon formed a boil about 20 feet (6 m) in diameter and about 35 feet (10.5 m) deep. Enlargement of the boil was arrested by filling the cavity with an inverted filter of sand, gravel, and rock.

An investigation of the conditions that started the boil was commenced at once and a Board of Consultants was convened. Piezometer pipes were immediately installed at 500-foot (150 m) intervals along the downstream toe of the dam. These piezometer pipes showed excessive pressure in the pervious strata beneath the clay stratum. A maximum pressure head equivalent to a head of water 45 feet (14 m) above the ground surface was observed, and studies indicated that if the pressure was not relieved it would rise to a maximum of 70 feet (21 m) at full reservoir elevation. The Board of Consultants recommended that a system of relief wells be installed near the downstream toe which would insure reducing the hydrostatic head in the downstream area to a value less than 15 feet (4.6 m) above the ground surface.

7.3.3 **Temporary Relief Wells.** A temporary well system was installed under emergency conditions from materials which were on hand. Work was started on the first well by Government plant and hired labor until a contract could be negotiated with the Norbeck Drilling Company of Redfield, South Dakota (Contract No. W-631-eng-2765 dated 17 July 1942). The contractor then took over the drilling of the wells and Government forces continued on the installation of piezometer pipes. Wells were installed by wash boring method along range 20+00-D. A heavy drill mud, consisting of weathered shale

and bran, was used as a drill fluid. It was necessary to work continuously around the clock and the mud had to meet a specified density in order to keep the well from flowing wild as soon as the pervious strata was reached. As soon as the first few wells were installed and in operation, the pressure in the area decreased and drilling operations were less critical.

The procedure of drilling the well, installing casing and screen, and stabilizing are briefly described as follows: The hole was drilled open hole to a nominal depth that varied from 20 ft (6 m) to 50 ft (15 m) before casing was installed. Drilling was then resumed using a bit that just went inside the casing, and after drilling ahead of the casing from 10 to 30 feet (3 to 9 m), casing would be added and driven. The casing was driven until it was seated about 1 foot (0.3 m) into the pervious gravel strata. Drilling then continued through the pervious strata to the desired depth, and perforated casing (or screen) was set. A blank section approximately 5 feet (1.5 m) long was used on the upper end of the screen and extended into the upper casing. A band of burlap was fitted around the top of the blank section and served as a seal between the screen and riser casing. The wells installed were 6-, 8-, and 10-inch (150, 200, and 250 mm) iron pipe with screen sections made from pipe 2 inches (50 mm) smaller in diameter. The perforations of the screen section were made with a cutting torch and consisted of slots 3 inches (75 mm) long spaced 6 to 8 to the circumference and 6 inches (150 mm) center to center along the length of the pipe. The width of slot varied from 1/8 inch (3 mm) to ½-inch (13 mm) with larger slots being favored as the well installation proceeded. The larger size slot, however, proved to be hard to stabilize as only a small percent of the foundation material exceeded the ½-inch (13 mm) size. After the installation of the screen section, jetting rods were run to the bottom of the well and the heavy drill mud was jetted out allowing the well to flow. Considerable material from the foundation was initially discharged by some wells and in others the pervious strata had become mudded up and the wells produced only a small flow. The wells were cleaned out and stabilized by surging with air pressure. Air pressure was introduced intermittently to the screen area through pipes and this produced a violent surge in the well which washed out

all the drill mud and removed the fines from the filter area around the screen. After surging a well for several hours, the flow was clear under all normal operating conditions and the well produced a large discharge with very little drawdown loss into the screen.

7.3.4 Operation of Temporary Wells. The construction of the wells was completed in September 1942. As the wells were installed the pressure in the area decreased. A series of tests was performed on the well system during November of 1942. These tests demonstrated that the well system was adequate and also demonstrated the necessity of draining both the upper and lower gravel layers. A meeting of the Board of Consultants was called for the spring of 1943 to review the system after this period of stable operation. The Board of Consultants considered the system of relief wells as installed adequate for maximum reservoir conditions but recommended that a new system of more permanent wells be planned to replace the original wells as soon as material was available after the war. Plate 7-6A shows the hydraulic gradient through the dam at station 60+00 prior to, during, and after the installation of the temporary well system.

The temporary well system functioned without trouble until June 1944 when one well failed. This well gave a slight warning by discharging an occasional piece of gravel for some time preceding failure. Upon failure, the discharge from the well was reduced to about 15 percent of normal and soundings showed that the screen had collapsed.

Operations were started at once to mud back the well and remove the screen. It was impossible to recover the screen itself, but a 5-foot (1.5 m) unslotted section was recovered. This section showed serious deterioration, and upon being weighed it was found that two-thirds of the metal had wasted away. As it was impossible to recover the remainder of the screen, drilling operations were started and the old screen which was filled with gravel was drilled out. During the drilling operations it was discovered that the casing also was very thin. Therefore, in replacing the screen, a riser pipe the same size as the screen was extended to the surface and effective seal

with oakum was made between the two pipes at the ground surface. The flow from the well was less than that prior to failure, but this was expected due to the smaller size of riser pipe, and also because the new screen extended only into the upper gravel layer.

While work was proceeding on the failed well the adjoining well also failed. Soundings showed that the screen in this well had also collapsed. This well, upon failure, did not discharge any material, but the flow was reduced to a very small amount. As this well was not a heavy producer at any time it was decided to abandon it. Later three additional wells failed. They were also abandoned.

7.3.5 **Testing Materials for Permanent Wells.** Upon the failure of the first well, studies were commenced that were necessary for planning a more permanent well system. At the same time, it was considered advisable to install some new emergency relief wells in case other wells should fail and to install screens in all piezometer pipes along the downstream toe so they could act as emergency relief wells. Four new wells were installed.

In installing these emergency relief wells, it was planned to make use of different materials in some of the wells in order to test their durability in actual use. As a consequence, orders were placed for test samples of different kinds of material. Contact was made with a commercial well screens company to make up a composite well screen to include the following:

a. Standard brass tube extension on top.

b. Monel section.

c. Silicone reel brass section.

d. Everdur section.

e. Super nickel section.

f. Ambrae section.

g. Armco iron (double galvanized).

This screen was installed in well 17A. A galvanized screen was installed in well 13A, which tapped both gravel layers. A test brass riser pipe and screen section was installed in well 9A and this well also tapped both gravel layers. Ordinary iron pipe was used for screen and riser pipe for well 15A which also tapped both gravel layers.

In addition to installing various kinds of materials in the emergency wells, special studies of cathodic protection for wells were started. One well was equipped with cathodic protection. Another surface test was started which furnished different degrees of protection to small sections of pipe which were placed in a trough in the discharge basin of one of the wells. These samples were taken out and cleaned and weighed at regular intervals, and at the end of the test it was readily apparent that the unprotected specimen lost weight at a much greater rate than the protected samples and the greater the protection the less weight the sample lost.

In addition to these tests on metallic materials, investigations were made on nonmetallic materials for possible use in the wells. In the consideration of nonmetallic substances, commercial firms were contacted as to the availability of their product for use in well installations. Consideration was given to the possibility of using wood, glass, concrete, transite, tile, and plastics for well casing and screen. Samples of concrete and transite pipe were secured and hung in the top of a well to test the action of flowing well water on the material. Sections of plastic pipe were secured and slotted for screen and installed in one of the temporary wells inside the existing screen as an auxiliary screen. The plastic was not as strong as expected and was quite brittle. At the end of 3½ years of service in the well, the test section of plastic screen was removed and was apparently in the same condition as when installed. Several sections of 10- and 12-inch (250 and 300 mm) transite pipe were ordered. Working with the actual pipe in the machine shop, a slot design and method of coupling the pipe together with a flush joint was developed. However, these tests were not carried further due to the fact that it was decided at this time to use wood pipe for the permanent well installation.

7.3.6. **Design of Permanent Well System.** Preliminary studies for the actual design of a permanent well system were started in 1945. It was desired that in designing a permanent well system it should at least equal the performance of the temporary system which had proven itself adequate. A study indicted there would be no decided advantage in moving the wells closer to the toe. Also, when considered from the construction point of view, it was advantageous to locate the new wells so the existing discharge ditch could be used. Also, the old wells could be salvaged as piezometers. With this in view, the new wells were located on the same line as the old wells. Another advantage was that more complete foundation data was available along this line.

At the meeting of the Board of Consultants for the Garrision and Oahe Dams at Bismarck, North Dakota, on 10 September 1945, preliminary plans for the permanent relief wells for Fort Peck were discussed informally with representatives of OCE and MRD. At this discussion wood pipe was recommended very strongly as an ideal material which would be resistant to corrosion, and it was suggested that studies be made as to its use for the permanent well system at Fort Peck. It was also recommended that in view of the past performance of the temporary well system that the same well spacing of 125 feet be retained for the permanent well system.

As soon as the wood pipe was received work was started on the design of slots and methods of coupling the pipe together. It was recognized that wood pipe would not be suitable if subjected to alternate wetting and drying. Therefore, transition section was designed so a change could be made to corrosion-resistant metal above the saturation line. The slot design and machine for cutting the slots, the couplings, bail plug, and transition section were designed and worked out at Fort Peck on the actual wood pipe. Originally, a vertical slot was planned but when a later shipment of pipe was received with closer spaced wire banding, an alternate horizontal slot design was developed.

7.3.7 **Installation of Permanent Pressure Relief Wells.** The contract for the relief wells at the downstream toe of the Fort Peck Dam, W24-016-eng-82, was awarded to Joel Norling of Billings, Montana, on 27 April 1945. The drilling details for each well are available in the drill log for each well.

The contractor chose to use cable tools and spudding bit for the drilling of the relief wells. Drilling operations started on 14 June 1946. Surface strata of sand was drilled without trouble and the hole was cased with 12-inch casing as drilling proceeded. When the layer of bentonitic clay was reached at about the 30-foot (9 m) depth progress stopped. The material kept squeezing in and after drilling awhile large amounts of mud could be bailed from the hole. Finally, after several days of drilling, enough material was removed so there was a subsidence of the area around the casing.

It was concluded that the bentonitic clay could not be drilled by cable tools using a spudding bit. Operations were closed down and the contractor changed over to jetting equipment on a trial basis. The drilling then progressed rapidly but there was considerable delay in securing samples. It was finally decided to discontinue sampling and the contractor rented a suitable pump and related jetting equipment which was used for the remainder of the job. The following procedure was followed in general for the installation of the remainder of permanent pressure relief wells. The contractor used commercial bentonite as drill mud, and while drilling through the clay layer, additional mud was made from the drilling operation. The holes were drilled open hole from the surface to the desired depth. Ten-inch (250 mm) drill casing was then installed and driven until seated in firm material. At times the hole had to be reamed out in order to install the casing to grade. After the casing was seated in the clay or shale foundation, the drill mud was jetted out of the pipe. The wood screen and pipe was then assembled and installed so that the screen sections matched the pervious foundation. The wood pipe was buoyant and had to be forced into place and then held down by inserting several lengths of drill pipe for weight. The water in the pipe was then replaced with drill mud in order to keep the well from flowing as the temporary drill casing was removed. The

temporary casing usually had to be started with jacks due to material caving in around the pipe. After pulling a few feet with jacks, the remainder of the temporary casing was pulled with the drill rig. Drill mud was added as the casing was removed.

After the temporary drill casing was removed, the annular space between the permanent wood pipe and the surface of the hole was grouted. Grout pipe was inserted to a depth of 19 feet (6 m) below the ground surface and grouting was started at this elevation. The grout used was composed of equal parts of sand and cement with sufficient water added for workability. When the hole would not take grout by gravity, air pressure was used to force the grout through the grout pipe. The wells took varying amounts of grout with the average being approximately 13 cubic feet (0.4 m^3) per well. After grouting was completed, a concrete block was placed around the transition section. This block tied into the grouting below. After pouring the concrete block, the well was allowed to stand for a couple of days before the mud was jetted out and the well allowed to flow.

The surging of the well usually began as soon as it started to flow. Air pressure was introduced through 2-inch (50 mm) pipes at about 2-foot (0.6 m) intervals of elevation for the entire length of screen section. The surges of air were introduced at varying time intervals but usually averaged about 30 surges per hour. For the entire job the average was 8 hours of surging for each well which included time required for setting up and dismantling of the equipment required for this work. After the surging was completed, the flow from each well was clear and no sand, silt, or clay was discharged.

7.3.8 **Summary of Observation Data.** Plate 7-7 presents a plan view and profile of the permanent pressure relief well installations and the emergency wells that were salvaged as permanent piezometers. The original system of 21 emergency pressure relief wells was installed along range 20 in 1942 to relieve excessive hydrostatic pressure along the downstream toe. Plate 7-8

shows a typical well installation. Plates 7-9 through 7-18 show the overall observation history of the pressure relief well system between 1942 and 1982. In general, these data show a decease in well discharge each year through 1953; after 1953, the reservoir was drawn down to near minimum pool elevation and did not again reach normal operating range until 1964; and after 1965, the well discharge continued to decrease but at a much slower rate than before 1953.

7.4 **DOWNSTREAM PRESSURE WELLS AND PIEZOMETERS.** Piezometers were installed during 1939 and 1940 along sections at stations 35+00 and 60+00, to measure the hydrostatic pressure in the foundation gravel that exists between the bedrock and the overlying clay stratum. Additional piezometers were installed in 1942 along a section at station 70+00 and in 1951 at station 50+00. The overall pressure pattern is shown on plate 7-19. This pressure pattern has shown little change with time and its prime value is to indicate the location along the sheet pile cutoff wall where most of the seepage is coming through. This location appears to be between station 50+00 and station 55+00, where the drop across the sheet pile wall is a minimum value. Plates 7-20 through 7-27 show the hydrostatic pressure record beneath the clay stratum through May 1982 along sections of stations 35+00, 50+00, 60+00, and 70+00.

7.5 **HEAD LOSS THROUGH SHEET PILING.** Initially, the head loss through the sheet piling was determined by graphically plotting the piezometer observations on a section and measuring the drop across the sheet piling. It soon became evident that the graphically determined head loss varied with the pool elevation even though there was a steady increase in head loss when data from a number of years were compared. It was therefore considered advantageous to have a mathematical procedure for determining head loss that would eliminate fluctuation based on pool evaluation. By expressing head loss across the sheet pile as equivalent foundation length, it was determined that fluctuations were eliminated and that the analyses of increases in a

sheet pile effectiveness with time was easier. This procedure is illustrated on plates 7-35 through 7-42.

The data presented on plates 7-39 and 7-40 for the section at station 60+00 is considered to be most representative as this section is near the center of the foundation area drained by the pressure relief wells. The effectiveness of the sheet piling at this section, expressed as equivalent foundation length, increased at about 115 feet (35 m) per year between 1942 and 1962. From 1962 to 1982, the increase averaged 30 feet (9 m) per year. Plates 7-37 and 7-38 present the record for the section at station 50+00. This section is very close to the point of minimum drop across the sheet piling. The record indicates that the head loss, expressed as equivalent length of foundation, has varied and even decreased for short periods of time. For the overall period between 1951 and 1970, there was, however, a gradual increase which averaged 21 feet (6.4 m) per year. From 1970 to 1982, there was no significant change in the head loss. In general, these graphs indicate that there has been a gradual increase in the effectiveness of the sheet pile wall through May 1982.

7.6 **ANALYSIS OF SEEPAGE PERFORMANCE.** Plates 7-35 through 7-42 also show the seepage performance of the foundation at the four representative sections of the dam. The observation data are mathematically analyzed for each observation date and the results of these analyses are plotted on each plate. The section at the top of each plate shows a graphical representation of the observation data for a representative date. The time graph plotted below furnishes a continuous record of the data. In most cases, an average line has been drawn through the plotted data to represent as closely as possible the average trend or condition at any time even though there may be considerable variation in plotted points. These data represent foundation conditions after the installation of the emergency pressure relief well system in 1942. The line of wells is considered to be the origin for foundation resistance. All distances shown on the graphs are measured from the line of wells. The "total foundation resistance" line shown on the graph

is the point where the hydraulic gradient extended from the upstream side of the sheet piling intersects the reservoir surface. A horizontal line has been drawn across each graph, except at station 50+00, which represents the average total foundation resistance at the start of pressure relief well operation. The difference between this horizontal line and the line drawn through the plotted points represents the increase in foundation resistance since the installation of the wells. It is believed that the increased upstream resistance is due to sedimentation and compaction of blanket material over the pervious zone by the downward seepage gradient. The total head loss expressed as foundation resistance includes the extra foundation length due to sheet piling. The total head loss expressed as foundation resistance and the upstream foundation resistance have increased over the years and the total increase from start of observation through January 1982 for each of the four sections is presented on tables 7-1 and 7-2.

TABLE 7-1

INCREASE IN TOTAL HEAD LOSS (EXPRESSED AS FOUNDATION RESISTANCE)

Station	1943 ft/m	1951 ft/m	1981 ft/m	Total Increase ft/m
35+00	6,400/1,950		12,900/3,950	6,500/1,985
50+00		5,900/1,800	6,500/1,980	600/180
60+00	6,700/2,045		10,500/3,200	3,800/1,160
70+00	9,300/2,840		15,400/4,700 1/	6,100/1,860

1/ Upstream piezometer under water since 1976.

TABLE 7-2

INCREASE IN FOUNDATION RESISTANCE

Station	1943 ft/m	1951 ft/m	1981 ft/m	Total Increase ft/m
35+00	5,400/1,647		6,300/1,920	900/275
50+00		5,300/1,615	5,700/1,740	400/122
60+00	5,800/1,770		6,600/2,015	800/245
70+00	6,500/1,980		8,400/2,560 1/	1,900/580

1/ Upstream piezometer under water since 1976.

7.6.1 **Conclusions.** The seepage performance data indicate that seepage conditions improved with time after reservoir operations commenced. If the cutoff wall should become entirely ineffective at some future date, the existing relief well system along the downstream toe is adequate to provide underseepage control of the deep pervious strata without the benefit of the sheet pile cutoff wall.

7.7 **HEAD LOSS THROUGH SHEET PILING ABOVE CLAY STRATUM.** As shown by the underseepage data presented on plates 7-43 through 7-46 for the years 1942 through 1982, the steel sheet piling cutoff wall serves as a rather positive cutoff in the semipervious zone between the core of the dam and the top of the clay stratum. This zone varies in thickness and permeability but would be capable of transmitting considerable seepage if it were not cut off by the sheet piling. The upstream sand shell transmits pressure to the upstream side of the core. Therefore, the hydrostatic head in this area is close to reservoir pressure. Piezometer installations upstream and downstream from the sheet piling indicate a large drop across the cutoff wall. The upstream piezometers register a hydrostatic pressure which is only slightly less than reservoir elevation and varies with the reservoir. The downstream piezometers vary only slightly and reflect the downstream water table projected back to the cutoff wall at a very slight hydraulic gradient. The records indicate that the cutoff wall is very effective in this zone and there are no indications of failure. If the cutoff wall becomes ineffective at some future date, however, the toe drain discharge would increase considerably and a more effective toe drain installation would be necessary.

7.8 **LEFT ABUTMENT PORE PRESSURE.** A report prepared about 1941 entitled "Report on Investigation of Hydrostatic Pressures In the Foundation Shale under the Fort Peck Dam" covered the pore pressure investigation of the foundation of the Fort Peck Dam that was made as a result of the slide investigations. A few of the installations were left in place for future observations. Plates 7-47 and 7-48 show the embankment foundation cross section and the results of all observations between 1940 and 1982. The cross

section shows the location of each piezometer and the zone where the pore pressure is being measured. The most spectacular of the pore pressure piezometers is FU 78.94/05 which had maintained a pressure which exceeded the crest of the dam by about 50 feet (15 m) until 1966. The graph indicates the pressure was decreasing at the rate of about 1.5 feet (.05 m) per year for periods when the reservoir has averaged about the same elevation. During the early years when monthly obervations were made, it was evident that the weight of the reservoir was reflected as pore pressure. In 1966, this piezometer was uncapped and allowed to discharge at a stabilized rate of 2 gallons (7.6 liters (L)) per day. During 1970, the pipe was capped and pressure observed for a 3-month period. The stabilized pressure indicated a head loss of about 10 feet (3 m) or a loss of head of slightly over 2 feet (.6 m) per year for this period of discharge. This uncapped piezometer is presently discharging at a stabilzed rate of about 1.0 gallon (3.8 L) per day. These piezometers should be observed as long as the hole stays open and the pipe is in condition to be observed.

7.9 **RIGHT ABUTMENT "A" FAULT INVESTIGATION.** The "A" fault was thoroughly investigated during the slide investigation and certain piezometers were left in place for future observation. The plan and sections, shown on plates 7-49 and 7-50, indicate the location of the "A" fault and the piezometers. The sections also show the location of numerous additional holes which were drilled to thoroughly investigate the fault. Piezometer PU 7.99/0.67 which is upstream from the core was rehabilitated in 1946 and a slotted 2-inch pipe with sand backfill around the screen was installed through the fault area. From 1946 to 1982, the hydrostatic pressure shown in this piezometer has averaged close to reservoir elevation. The downstream piezometers indicate the gradient through the fault. Downstream from the core, the surface exposure of the fault is covered with clean pervious sand shell material which can safely take care of any seepage finding its way through the fault. The record of the piezometers as shown on plates 7-49 and 7-50 indicates there have been no changes during years which could be of concern. After the slide, a report was forwarded to the Board of Consultants entitled "Report on Investigation to Determine Permeability of 'A' Fault in Right Abutment of

Fort Peck Dam." No copies of this report are available but it is summarized in reference 43. In general, it was concluded there was little chance of appreciable seepage developing through this fault zone, but piezometers would be maintained as long as possible to keep check on hydrostatic conditions in the fault area.

7.10 **CORE INVESTIGATION AT STATION 35+00.** During 1944 and 1945 a number of piezometers were installed in the core section of the dam at Station 35+00 to determine the true effectiveness and pressure contour pattern through the core section. Plates 7-51 and 7-52 summarize conditions for the period from 1945 to 1982. Graphs to the right of each plate show the time record of each individual piezometer for the period of record. The location of the bottom of each piezometer is shown on the section to the left of each plate. The contours were drawn from this available data and the saturation line downstream of the core was determined from perforated seepage pipe data. These contours are considered representative of conditions in the core section of the dam and indicate the core section is performing effectively. During 1977, when the pool was receding from the relatively elevated level, several piezometers indicated questionable increases in pressure. Numerous piezometers which had not been read for a number of years, but not formally abandoned, were read as a comparison to those being actively read. All core piezometers were closely observed for several months following the incident. A concentrated program was initiated to check the effectiveness of all existing project piezometers. It was detemined that several of the questionable instruments were indeed inoperative. However, relatively high pressure increases indicated by PD 35/1.4 and PD 35/1.7 could not be attributed entirely to their operational condition. It was assumed that the embankment was slowly feeling the effects of the 1975 and 1976 elevated pool period. The phreatic surface within the embankment drops sharply as it penetrates the zone 4 shell, substantiating its relative drainage characteristics. The piezometers located within the zone 4 material are subject to substantial fluctuation with pool changes, although they may lag by several months time.

7.11 **MISCELLANEOUS OBSERVATIONS.** Seepage pipes are perforated pipe installed in the hydraulic fill and designed to determine the average saturation or phreatic line in the fill. The pipes consist of 4-inch perforated iron pipe and all pipes were set so the bottom was below the saturation line. These installations should have a long life as nothing short of collapse should take them out of service. They were flushed and cleaned several times after installation but have now served from 1956 to 1982 without maintenance. Plate 7-53 shows the locations of all seepage pipes and plates 7-54 through 7-71 show observation data from 1947 to 1982. Plate 7-72 is a pressure contour map showing the hydrostatic pressure above the clay stratum for the area downstream from the core of the dam and also includes the area downstream from the dam to about range 30 downstream. Plate 7-73 shows the details of the presently installed toe drain after repairs were completed in 1958. Plate 7-74 shows the toe drain discharge fluctuation from 1960 to 1982. The discharge correlates well with pool elevation and it does not appear that there is a lessening of the toe drain system's effectiveness.

Saturation line observations at embankment stations 115+00, 145+00, and 165+00 are presented on plates 7-75 through 7-80. These data, which cover the period between 1947 and 1982, indicate that the saturation line downstream from the dike has been slowly rising since the reservoir has been at the present high operating level which started in 1965. This area has been under constant observation since June 1965 when a number of observation points were established to check on seepage in this area. It is possible that, in the future, a drain may have to be installed along the toe of the dike.

SECTION VIII - EMBANKMENT MOVEMENT OBSERVATIONS

8.1 GENERAL. Reference 43 covers the embankment and foundation movements to 1957 and should be referred to for the details of the various monuments and the history of their installation and observation. In general, movement observations were started in 1935 when embankment construction was started. These installations were brought up through the embankment and observations continue to the present date. Settlement monuments were installed on the crest as the embankment neared completion; these installations were used for both horizontal and vertical movement observations. Numerous tabular and graphical records are kept up to date which show the movement of the dam and foundation at all observation points. This review of movement will consist of selected graphs and plates summarizing the movement to date.

8.2 EMBANKMENT MOVEMENT OBSERVATIONS

8.2.1 Embankment and Dike Motion. The location plan of benchmarks and embankment settlement and foundation subsidence pipes is presented on plate 8-1. The record of crest settlement and time/movement plots are shown on plate 8-2.

Horizonal control record of the crest and toe movement monuments is plotted on plate 8-3.

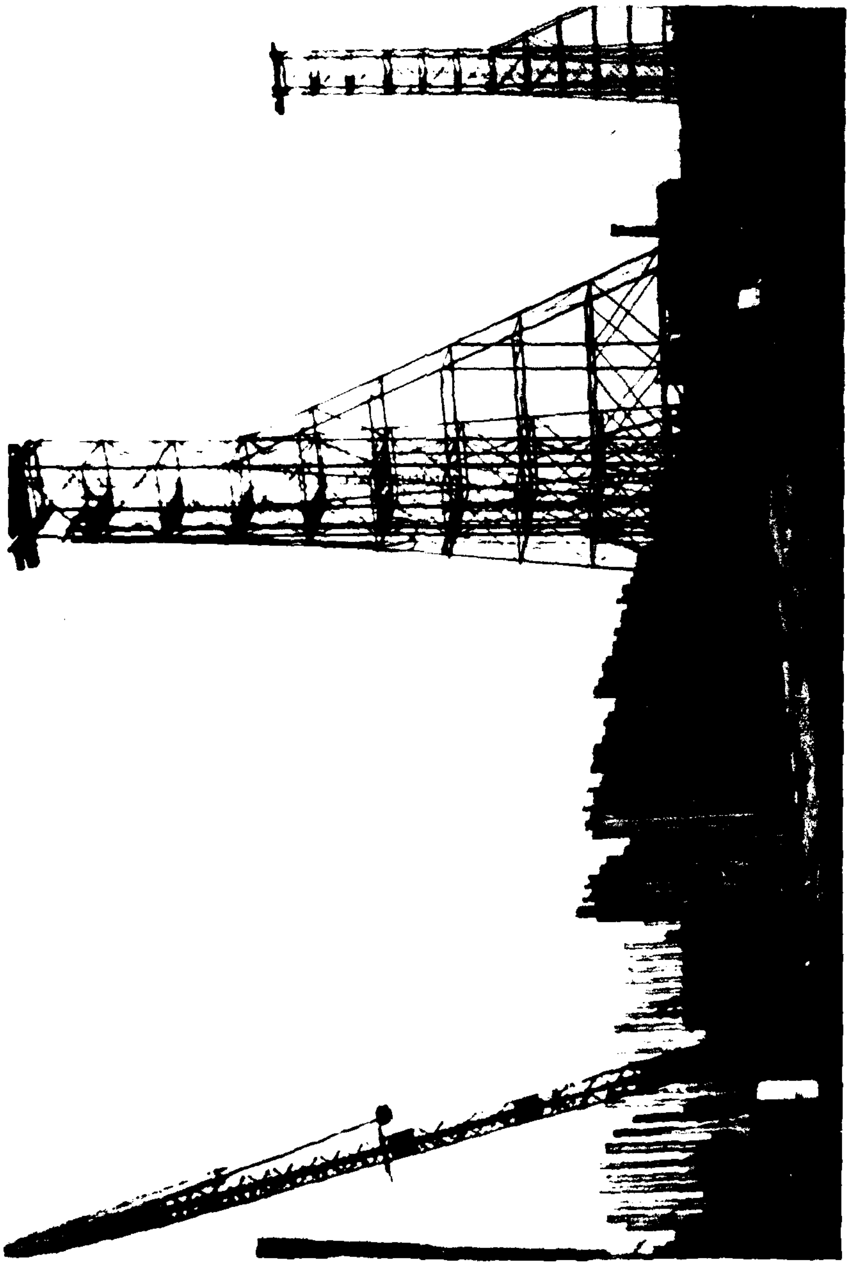
The record of dike settlement is presented on plates numbers 8-4 and 8-5. Settlement of this left embankment extension has been minor since 1965.

8.2.2 Foundation Settlement Record. Foundation settlement data are shown on plates 8-6 through 8-13. Recent surveys indicate no significant change in the measured foundation subsidence.

8.2.3 Tiltmeter Observations. A single tiltmeter was installed in 1973 to monitor creep in the valley alluvium as well as horizontal motion in the embankment. To date, no appreciable motion has been noted.

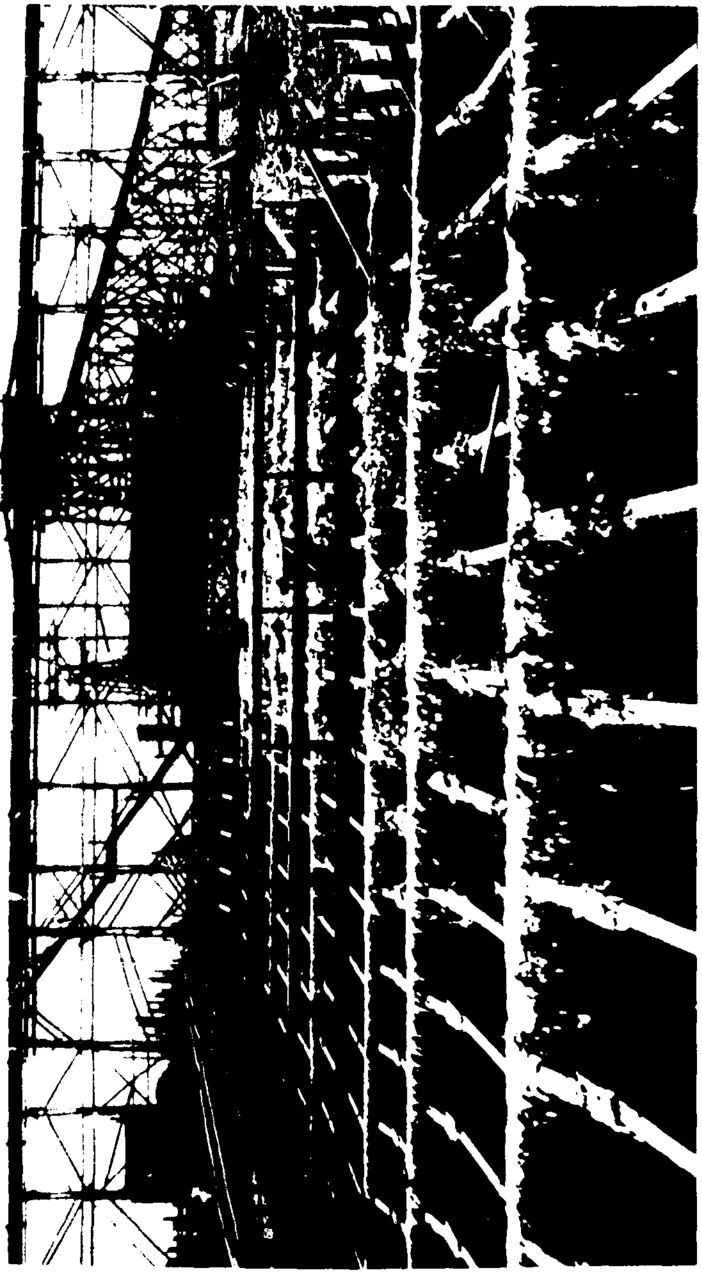
APPENDIX A

PHOTOGRAPHS



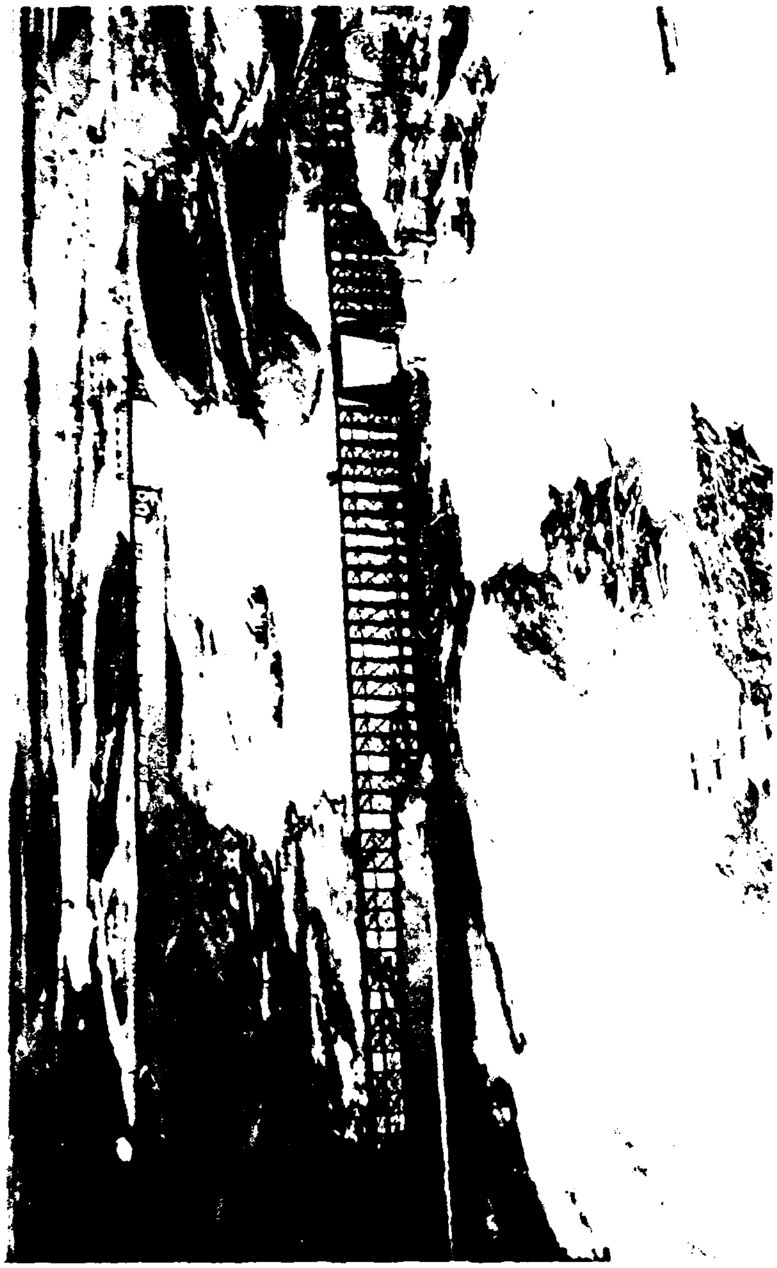
View of upper portion of sheetpile cutoff wall installed 37.5 feet upstream of the dam axis between stations 2 + 00 in the right abutment to 103 + 50 in the left abutment. The top 20 feet of the piles were subsequently embedded in the impervious core of the hydraulic fill.

Material was pumped by dredges through pipes to construct the dam. The fill material ws released from the pipelines of selected locations along the line by opening small ports on the bottom of the pipe. Heavier gravel and sand materials were deposited adjacent to the pipeline.



Fine sand, silt and clay settled in a core pool at the end of the pipeline and formed the impervious core of the dam.

The remaining water and very fine materials were discharged to the river by means of these cascading spillways.



View of ''Closure'' section of dam embankment.

FORT PECK DAM, MONTANA
EMBANKMENT CRITERIA
AND PERFORMANCE REPORT

PLATE A-5

Control gates over tunnels are almost completed. This view is looking west along axis of dam. Note core pool from dredge material on dam. This water eventually drained back out to Missouri River channel.

Embankment complete except for closure section. This view looking northwest of Missouri River channel

AD-A123 607 EMBANKMENT CRITERIA AND PERFORMANCE REPORT MISSOURI RIVER FORT PECK LAKE..(U) ARMY ENGINEER DISTRICT OMAHA NEBR SEP 82

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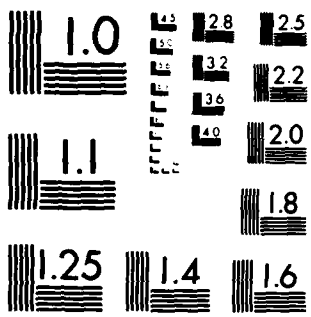


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

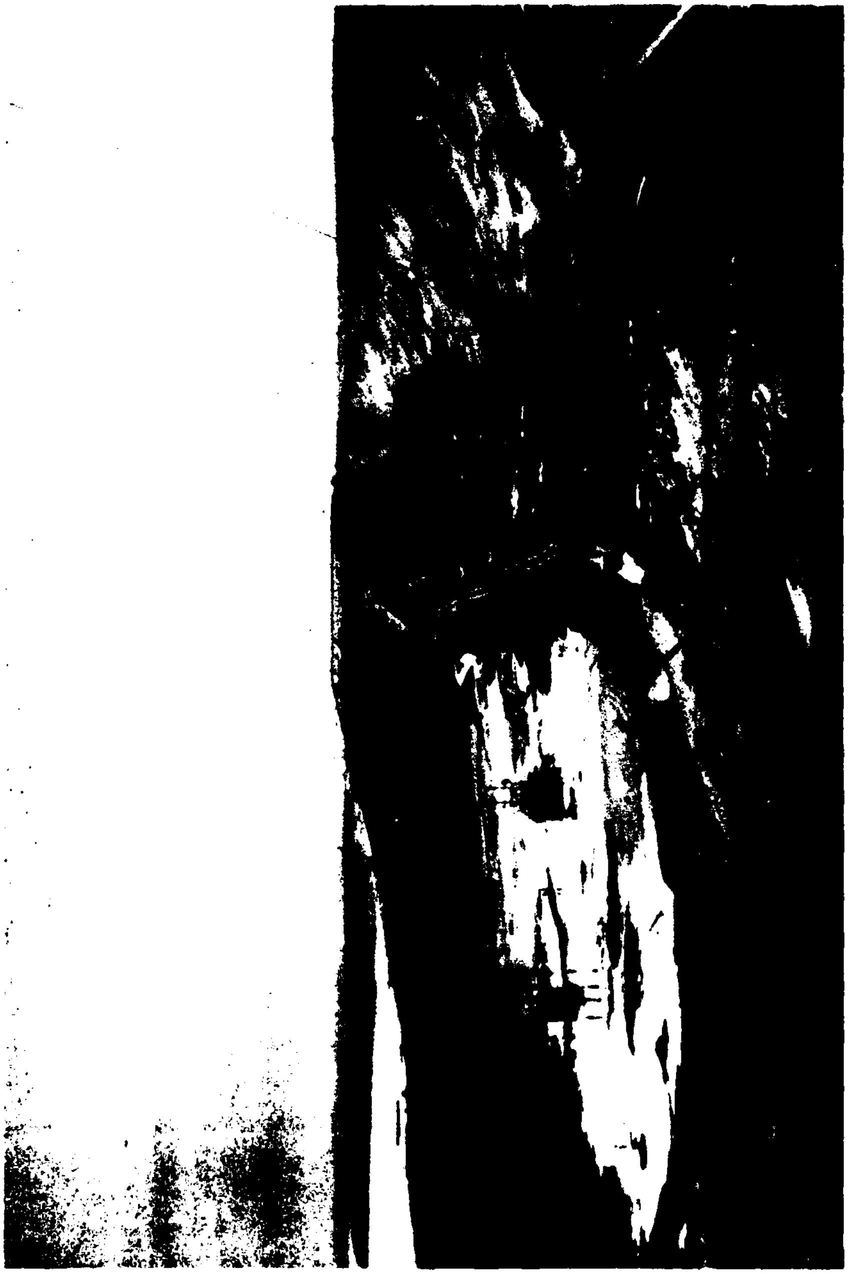
Blasting of temporary dike at the diversion tunnel inlets, prior to closure operations on 24 June 1937. Diversion was completed 28 minutes after the temporary dike was dynamited.

View of closure operations. A total of 140 carloads of gravel (over 5,600 cu. yds.) were dumped in two hours. The closure involved dumping a total of 11,500 cu. yds. of field stone and gravel.

Aerial view of Fort Peck Dam at right abutment about three months prior to slide. Reservoir elevation 2127.2; Core pool elevation 2211.0. (29 June 1938).

Aerial view of 22 September 1938 slide that occurred on the upstream face of the dam. Approximately 5,000,000 cu. yds. of material was moved in the slide.

Vertical aerial view showing extent of damage to Fort Peck Dam resulting from the 22 September 1938 slide.



The damaged area of the dam was reconstructed with a narrow core compacted using rolled fill methods. The old and new core were connected by means of steel sheet piling. The width of the dam was increased by the addition of an up-stream stabilizing berm.

APPENDIX B

BIBLIOGRAPHY OF REFERENCE DATA

MISSOURI RIVER

FORT PECK LAKE, MONTANA

BIBLIOGRAPHY OF REFERENCE DATA

(AVAILABLE IN OMAHA DISTRICT OFFICE)

Miscellaneous Reports and Memorandums

	Subject	Date
1.	Cost Estimates, Fort Peck Dam and Reservoir Project Used in 308 Report	
2.	Excerpts from Appendix IX to 308 Report, Main Stem of Missouri River and Minor Tributaries	
3.	Letter of Transmittal of Cost of Earth Dam on the Missouri River near Fort Peck, Montana	14 October 1933
4.	Preliminary Report on Practicability of Proposed Fort Peck Reservoir from the District Engineer	23 October 1933
5.	Letter of Approval for Construction Plan for Fort Peck Reservoir from Chief of Engineers	24 November 1933
6.	Construction Plan for Fort Peck Reservoir from the District Engineer	31 October 1933
7.	Minutes of the Board Meeting	27 November 1933
8.	Minutes of the Board Meeting	28 November 1933
9.	Preliminary Report on the Geology of the Fort Peck Dam Site. Chester K. Wentworth	26 September 1933
10.	Report on Fort Peck Dam Design. D. C. Henry	8 December 1933

	Subject	Date
11.	Letter dated 18 January 1934 Transmitting the Minutes of Board Meeting	11-12 January 1934
12.	Minutes of Board Meeting	12 March 1934
13.	Minutes of Meeting of Consultants	16 April 1934
14.	Minutes of Meeting of Consultants	25 July 1934
15.	Fort Peck Spillways from the Division Engineer	3 August 1934
16.	Minutes of Meeting of Consultants	24 August 1934
17.	Letter dated 17 April 1935 Transmitting the Minutes of Board Meeting	8-10 April 1935
18.	Minutes of Meeting of Consultants	10 June 1935
19.	Report on Methods of Determining the Stability of Embankments. The Soil and Fill Control Division of the United States Engineer Office, Fort Peck, Montana	May 1938
20.	Data on Slide Investigation	7 October 1938
21.	Fort Peck Dam Slide Investigation	19 November 1938
22.	Report of Board of Engineers for Fort Peck Dam	13 February 1939
23.	Report of Board of Engineers for Fort Peck Dam	3 March 1939
24.	Report on Design of Fort Peck Power Development from the Division Engineer	31 March 1939

Subject	Date
25. Report of Board of Consultants, Fort Peck Dam	17 June 1939
26. Report of Inspections. Dr. Gilroy and Mr. Irving B. Crosby	24 August 1939
27. Report of Consultants	25 September 1939
28. Notes on Consultants' Meeting	30 June 1942
29. Seepage and Hydrostatic Pressure at Downstream Toe of Fort Peck Dam	1 July 1942

Special Reports

30. Fort Peck Dam - Computations for Stability	1935
31. Report on the Slide of a Portion of the Upstream Face of the Fort Peck Dam	July 1939
32. Report on Head Loss Through Sheet Pile Cutoff Wall at Fort Peck Dam	July 1949
33. Report on Improvement of Relief Well Design at Fort Peck Dam	June 1951
34. Report on Powerhouse Slope and Outlet Portal Wall Movement Studies at Fort Peck Dam	October 1959
35. Report on Existing Toe Drain at Fort Peck Dam	May 1961
36. Report on Spillway Movement Observations of Fort Peck Dam	September 1971
37. Movement Observations First and Second Powerplants, Fort Peck Dam	January 1963

Subject	Date
38. Rock Strength from Failure Cases: Powerhouse Slope Stability Study, Fort Peck Dam (Hamel)	September 1971
39. Dynamic Analysis of Fort Peck Dam, U.S. Army Engineer Waterways Experiment Station Technical Report S-76-1	March 1976

Periodic Inspection Reports - Dam, Spillway, Outlet Works, and Powerplants

40. Periodic Inspection Report No. 1	August 1971
41. Periodic Inspection Report No. 2	June 1974
42. Periodic Inspection Report No. 3	August 1979

Operation and Maintenance Manuals

43. Embankment	September 1957
44. Spillway	September 1957
45. Powerplant No. 1, Volumes I, II, and III	September 1957
46. Diversion Tunnels	September 1957
47. Powerplant No. 2, Volumes I and II	1970
48. Appendix E - Contingency Plan for Emergencies	

Design Memorandums

	Number	Title	Date Submitted	Date Approved
49.	1	Modifications to Control Shaft		-
50.	-	Tunnel No. 3	February 1955	-
51.	-	Supplement	June 1955	-
52.	-	Model Testing, Modification of Control Shafts Tunnel No. 4	July 1959	-
53.	MFP-1-99	Unassigned		-
54.	MFP-100	Report on Analysis of Design Second Powerplant	July 1959	-
55.	MFP-101	Recreational Facilities Proposed for FY 1961	January 1961	February 1961
56.	MFP-102	Modification to Transformer Untanking Facilities Power Plant No. 1	June 1961	July 1961
57.	MFP-103	Additional Recreational Facilities	May 1962	June 1962
58.	MFP-104	Permanent Housing and Related Facilities	January 1964	-
59.	MFP-105B	Public Use Facilities	December 1963	April 1964
60.	MFP-105C	Master Plan	September 1965	June 1966

	Number	Title	Date Submitted	Date Approved
61.	MFP-106	Spillway Gate Structure Downstream Joint Repair	February 1964	May 1964
62.	MFP-107	On-Project Signs	April 1964	May 1964
63.	MFP-108	Permanent Housing and Related Facilities	November 1964	August 1965
64.	MFP-109	Appraisal and Rehabilitation of Downstream Portion of Fort Peck Spillway	June 1965	March 1967
65.	MFP-110	Intake Structure Bulkhead	August 1966	August 1968
66.	MFP-111	Hell Creek Access Road	April 1967	May 1968
67.	MFP-112	Service Road Rehabilitation Dam and Vicinity	March 1969	October 1969
68.	MFP-113	Spillway Slope Excavation, Stage II	April 1970	June 1970
69.	MFP-114	Additional Storage, Shopping Center	August 1970	September 1970
70.	MFP-115	Miscellaneous Rehabilitation Powerhouse - Spillway Areas	November 1971	January 1972
71.	MFP-117	Richardson Coulee Line Terminal Revisions and Replacement 115 KV Disconnect Switches	July 1973	August 1973
72.	MFP-118	Spillway Slope Excavation	September 1973	-

	Number	Title	Date Submitted	Date Approved
73.	MFF-119	Derrick Boat Rehabilitation	October 1973	November 1973
	MFP-120	Unassigned		
74.	MFP-121	Convert Heating, Hotel	May 1976	-
75.	MFP-122	Reactor Switching	June 1976	July 1976
76.	MFP-123	General Thrust Bearing High Pressure Oil Lift System	October 1976	February 1977
77.	MFP-124	Outlet Works Modifications	August 1977	-
78.	MFP-125	Increased Power Output Capability for Units 4 and 5	March 1978	-
79.	MFP-126	Fishing Dock for Handicapped	November 1978	-
80.	MFP-127	Embankment Toe Drain	March 1980	Approval Not Required
81.	MFP-128	Utilities Building Replacement	March 1980	-
82.	MFP-105C	Appendix B of Master Plan	December 1977	Approved
83.	MFP-129	Galpin Coulee Erosion Control	April 1981	-
84.	MFP-130	Regrade Downstream Toe Area	November 1980	December 1980

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